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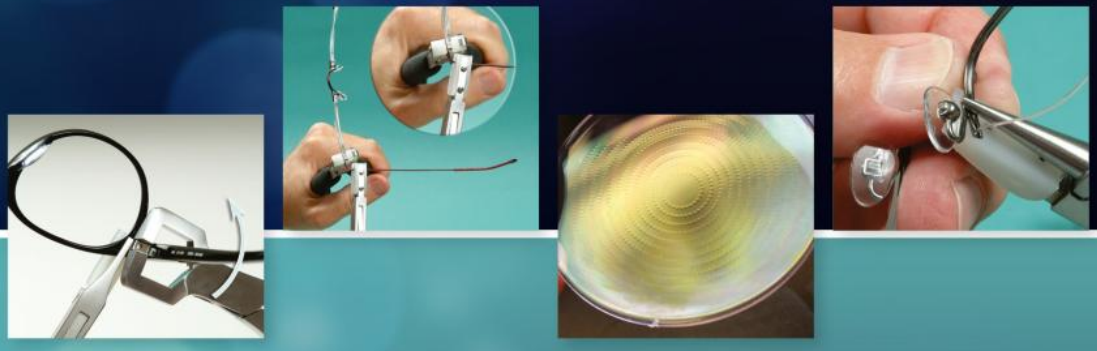

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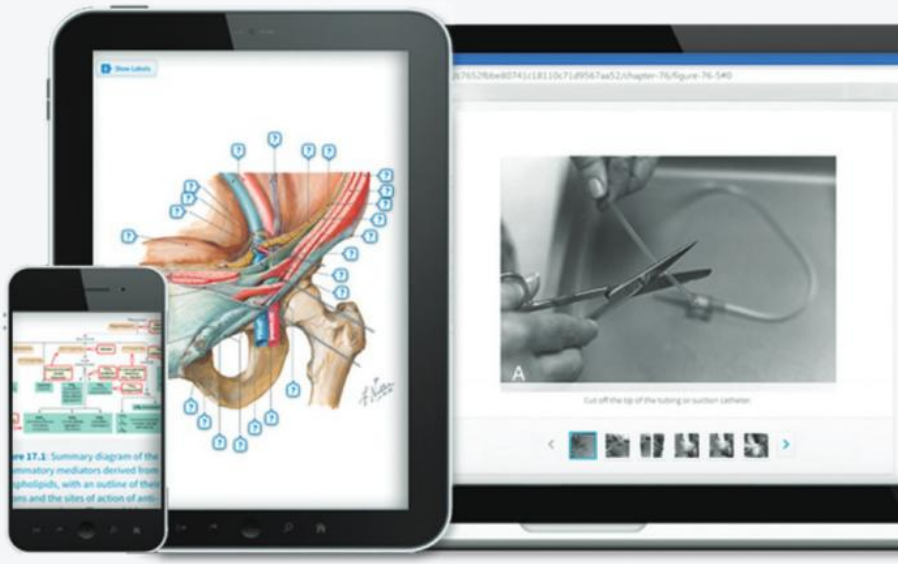

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System for

OPHTHALMIC DISPENSING

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System for OPHTHALMIC DISPENSING

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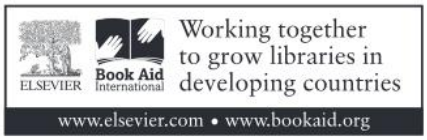

Dedication

This book is dedicated to our students, whose interest and desire to master the subject prompted its writing.

Remembering Dr. Borish

It is with much gratitude that we remember Dr. Irvin M. Borish. His mentorship, guidance, and valuable contributions while serving as co-author for previous editions of *System for Ophthalmic Dispensing* laid a strong and enduring foundation for this work. He will long be remembered for his legendary role in the eye care professions.

PREFACE

The original goal for creating *System for Ophthalmic Dispensing* was not to create a comprehensive textbook. Rather, we envisioned a student manual to aid in the teaching of how to dispense prescription eyewear. As the "manual" developed, Professional Press learned of the project, expressed an interest, and requested sample chapters. It became evident that such a publication might be useful beyond the confines of teaching at Indiana University.

Once a preliminary manuscript copy was available, it was sent out for review. This resulted in a request for the addition of material on the optics of lenses. Thus, a second section was added. Perhaps because of the large number of photographs and illustrations, the first edition was found to be useful both in educational programs and in ophthalmic practices.

The dispensing of eyewear and an understanding of how ophthalmic lenses perform are essential to both the new employee in the optical dispensary and the experienced eyecare practitioner. Knowing the varied backgrounds of the reading audience, an attempt was made to write in a manner that would be understandable to someone new to the field while including the type of information needed by those with years of ophthalmic experience.

The second edition built upon and updated the original edition, adding sections on lens material and lens design. The second edition contained large numbers of photos—all in black and white.

For the third edition, the decision was made to start over again with color photos. Hundreds of photos were taken, each from the viewing perspective of the eyecare provider. There were also major changes in the second half of the book concerning ophthalmic lenses.

The fourth edition incorporates much new material reflecting the growth of the ever-changing eyecare professions. In updating the content of each chapter, attention was also given to any need for new photos or illustrations and to improving the readability of the text for better understanding. The proficiency test at the end of each chapter not only identifies the correct answer but now includes a rationale.

As with all previous editions, the needs of two groups of professionals are of high importance. The first group consists of eyecare practitioners who must themselves stay current while simultaneously training new personnel. The second group is made up of ophthalmic educators and students in formalized educational programs. Both need well-illustrated, comprehensive educational resources.

As before, it is our hope that you will find this most recent edition of *System for Ophthalmic Dispensing* informative, easy to use, and personally beneficial.

ACKNOWLEDGMENTS

For help in preparing the first edition, special thanks go to Jacque Kubley for his original photography and illustrations; Sandra Corns Pickel and Sue Howard for serving as hand models; and Dr. Linda Dejmek, Kyu-Sun Rhee, Dennis Conway, and Steve Weiss for artwork and illustrations.

For the second edition, again thanks to Jacque Kubley for continued assistance in photography and graphics.

For his many helpful ideas and suggestions with both second and third editions, thanks go to Glenn Herringshaw, former manager of Indiana University's optical laboratory. A specific word of appreciation goes to Robert Woyton of Hilco Vision for reviewing the chapter on repairs and supplying a number of excellent photographs.

Thanks to Ric Cradick for taking a multitude of color photos for the third edition. His professional expertise is unmatched.

For the fourth edition thanks to Dr. Palmer Cook, Cincinnati, Ohio, for many lively and informative conversations on ophthalmic optics and for reviewing written material relevant to those conversations. For help in clarifying lens standards, base curves, and prism questions, heartfelt thanks go to Dick Whitney of Carl Zeiss Vision and the Optical Heritage Museum, Southbridge, Massachusetts.

Special thanks go to Dr. Geoffrey Goodfellow of Illinois College of Optometry for serving as Technical Editor. From the perspective of his students and as one who has a long history of teaching the subject, Dr. Goodfellow painstakingly worked to improve content and ensure the accuracy of all material in every chapter. His help in determining what to cut and what to add is invaluable.

Finally, special thanks to many friends within the professions for offering suggestions and supplying ideas for improving the text. Without your advice and information, it would have been impossible to complete the task.

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PART I

Ophthalmic Dispensing

1

Frame Types and Parts

BASIC PARTS

The frame is that portion of the spectacles that holds the ophthalmic lenses in their proper position in front of the eyes.

A frame generally consists of the *front*, which contains the lenses, and the *temples*, which attach to the frame front and hook over the ears. Frames occasionally do not have temples and are instead held in place by pressure on the sides of the nose (pince-nez) by attachment to another frame (clip-ons) or by being held in the hand (lorgnettes).

Frame Fronts

That area of the frame front between the lenses that rests on the nose is called the *bridge*. The rim going around the lenses is known as the *eyewire,* or *rim*. The outer areas of the frame front to the extreme left and right, where the temples attach, are known as the *endpieces.* A few plastic frames may still have a metal *shield* on the front of the endpiece to which rivets are attached to hold the hinge in place. However, most shields now are there only for looks and do not attach to the hinge (Figure 1.1).

The *hinges* hold the temples to the front and consist of an odd number of interfitting *barrels*; the total number may be three, five, or seven. Hinges may vary in construction but, for simplicity, are usually classified by the total number of barrels they have when assembled, such as a three-barrel hinge.

Some frames have *nose pads*, which are plastic pieces that rest on the nose to support the frame. These may be directly attached to the frame or to connecting metal pieces known as *guard arms* or *pad arms*.

Temples

The portion of the temple that is nearest its attachment to the frame front is known as the *butt portion,* or *butt end.* The place on the temple where it first bends downward to go over the ear is called the *bend*. The portion of the temple between the butt end and the bend is called the *shaft,* or *shank,* and that portion beyond the bend and behind the ear is referred to as the *earpiece*, *bent-down portion*, or *curl* (Figure 1.2).

CONSTRUCTION

Frames

Frames without an eyewire going completely around the lens are called *mountings*. Lenses are "inserted" into frames, but "mounted" into mountings. Frames themselves can be classified in a simplified manner by one of the following categories of frames or mountings.

Plastic

Plastic frames are made of some type of plastic material. Plastic frames were occasionally referred to as *shell* frames, dating back to the time when eyeglass frames were made of tortoise shell. This term has fallen into disuse. Another general term that may still be used for certain plastic frames is *zyl*. The name *zyl* continues to be used but usually refers to the most commonly used plastic material, which is cellulose acetate. Now, with the emergence of many new materials, either the exact name of the plastic material is used, or the frame is simply referred to as *plastic* (Figure 1.3).

Metal

Metal frames are those made of almost all metal parts, except for the nose pads and the posterior temple sections, which are plastic covered. The eyewire runs completely around the lens (Figure 1.4).

Nylon Cord Frames

Nylon cord frames, sometimes called *string-mounted frames* or *nylon supras,* hold the lenses in place by means of a nylon cord that fits into a groove cut into the edge of the lens. This gives the glasses the appearance of being rimless. Nylon cord frames are often classified as rimless, although they are really in a category by themselves. Usually the top of the lens is fitted into the upper rim of the frames. The lens has a small groove cut into an otherwise flat edge (Figure 1.5).

Combination

Combination frames are commonly frames having a metal *chassis* and plastic top rims and temples (Figure 1.6). The chassis includes the eyewire and center or bridge section. Although this is the most common construction, technically any frame with a combination of metal and plastic could be included in this category, as in the case of a frame with plastic eyewires and metal bridge and temples.

Half-Eyes

Half-eyes are frames made especially for those who need a reading correction but no correction for distance vision. They are constructed to sit lower on the nose than normal and have only half the vertical height of regular glasses. This allows the wearer to look over the top of the glasses. They may be of plastic, metal, or even nylon cord construction (Figure 1.7). Less common are half-eyes for distant vision, which allow the wearer to look under the lenses for reading.

Rimless and Semirimless

Rimless mountings hold the lenses in place by some method other than eyewires or nylon cords. A variety of holding methods such as screws, clamps, or plastic posts may be used. Most rimless mountings have two places of attachment per lens, one nasal and one temporal (Figure 1.8). In the past, rimless mountings were sometimes referred to as *three-piece mountings* because the mounting consists of three main pieces—the bridge and two endpieces.

Semirimless mountings are like rimless mountings except for a metal reinforcing *arm*, which follows the upper posterior surface of the lens and joins the *centerpiece* or bridge of the frame to the endpiece. The centerpiece of a mounting consists of bridge, pad arms, and pads (Figure 1.9).

Balgrip Mountings

Balgrip mountings are a variation of semirimless mountings and secure the lens in place with clips attached to a bar of tensile steel that fits into a nasal and a temporal notch on each side of the lens. The lens can be easily removed by pulling the clips away from the lens. For this reason, this type of mounting can be used with more than one pair of lenses for the same frame. Sunlenses, special purpose lenses, or tinted lenses could then be used interchangeably with the patient's regular lenses (Figure 1.10). Notches are sometimes used in combination with drilled holes in rimless mountings to lend stability to the mounting.

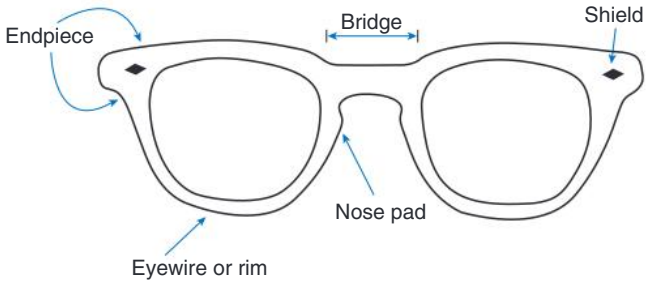

Figure 1.1 The frame front.

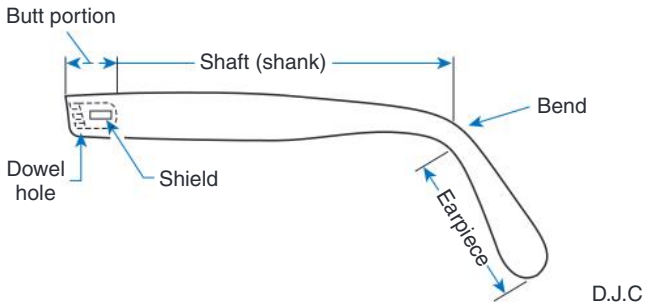

Figure 1.2 Parts of a temple.

Bridge Area

The bridge area of a frame can be constructed of either plastic or metal. Because of the variety of nose shapes, there is also quite an assortment of bridge constructions in both materials.

Plastic Bridges

The bridge area of a plastic frame is preformed and sits directly on the bridge of the nose. It is important, then, in picking out a plastic frame that the frame fit the nose well, since adjustments to this part of the frame are extremely difficult. Bridge adjustments for certain plastics, such as nylon, carbon fiber, and polyamide, are not possible.

Figure 1.5 A nylon cord frame or "string mount" holds the lens in place with a cord that fits around the edge of the grooved lens.

Figure 1.3 An example of a plastic frame.

Figure 1.4 One version of a metal frame.

Figure 1.6 Examples of combination frames.

Figure 1.7 Half-eye frames in use. Half-eyes are made especially for those who need a reading correction but no correction for distance vision.

Figure 1.8 An example of a rimless mounting. The central area of the frame is not connected to the endpieces. The only connecting points are the lenses themselves.

Figure 1.9 A semirimless mounting has a bar behind the top of the lens connecting the endpieces to the bridge area.

The *saddle bridge* is shaped like a saddle in a smooth curve and follows the bridge of the nose (Figure 1.11). This spreads the weight of the frame evenly over the sides and crest of the nose.

In the *modified saddle*, the bridge area looks much the same as the saddle bridge does when viewed from the front. The difference is that there are nose pads that are part of the back of the bridge. These pads help to carry some of the weight of the frame (Figure 1.12).

The *keyhole* bridge is shaped like an old-fashioned keyhole. At the top, the bridge flares out slightly. The bridge rests on the sides of the nose but not on the crest (Figure 1.13).

Metal Bridges

The bridge commonly used in metal frames is the *pad bridge* (see Figure 1.8). In the pad bridge, nose pads are attached to the frame by metal pad arms. In this case, the pads alone support the weight of the glasses.

When a metal frame is equipped with a clear plastic saddle-type bridge, the bridge type is referred to as a *comfort bridge*.

Metal and rimless frames were, and sometimes still are, constructed with a *metal saddle bridge* (Figure 1.14) and enjoyed widespread use for a period of history. It may yet occasionally appear exactly as before or decoratively in conjunction with nose pads.

Endpiece Construction

Endpiece construction, like bridge area construction, can be of either plastic or metal.

Plastic Endpiece Construction

There are three general types of endpiece construction in plastic frames (Figure 1.15). The most common endpiece construction is the *butt* type, in which the front is straight and the temple butt is flat. Both meet at a 90-degree angle. The *mitre* endpiece causes the frame front contact area and temple butt to meet at a 45-degree angle. In the *turn-back* type, the frame front bends around and meets the temple end to end.

Metal Endpiece Construction

The traditional metal endpiece has a construction like the turn-back endpiece of the plastic frame (Figure 1.16). There are a wide variety of metal endpiece designs.

Endpieces are also noticeable by their absence. Instead of an endpiece, some frame fronts and temples are made as one *continuous piece* (Figure 1.17).

Temple Construction

Temples also vary greatly in their construction. In general, there are five major categories (Figure 1.18).

1. *Skull temples* bend down behind the ear and follow the contour of the skull, resting evenly against it. The bent-down portion is narrower at the top of the ear and widens toward the end. This is typically the most common type of temple.

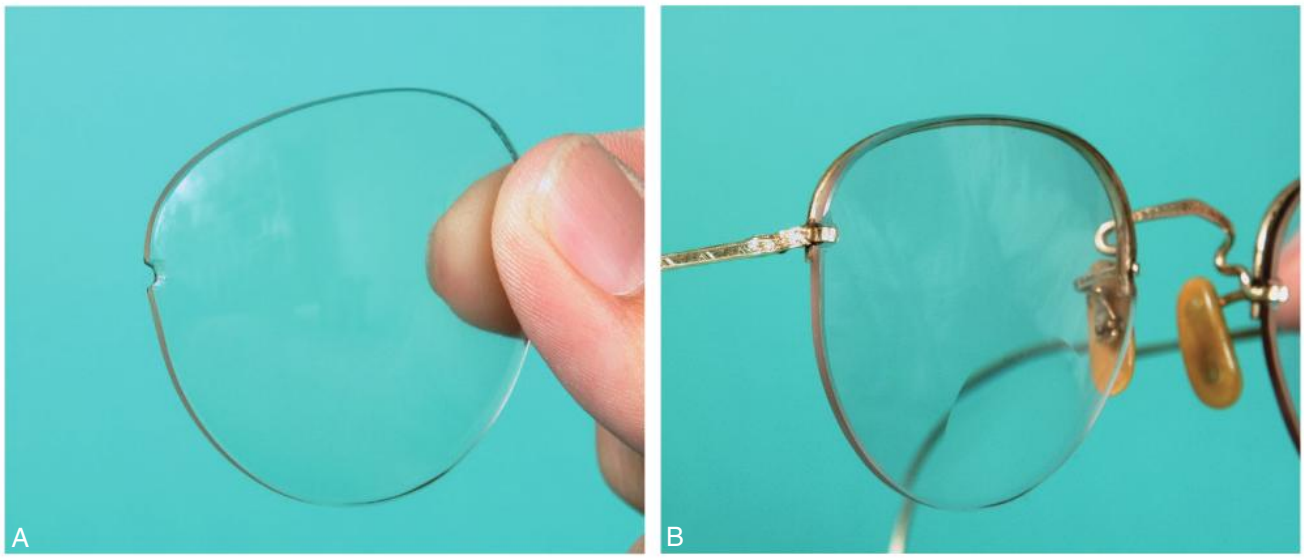

Figure 1.10 A balgrip mounting. In this form of rimless mounting, the slotted lenses shown in **A** are held in place with clips, as shown in **B**.

Figure 1.11 The saddle bridge closely follows the contour of the nose, evenly spreading the weight of the frame.

Figure 1.12 The modified saddle bridge has fixed nose pads attached at the back to increase the weight-bearing area of the frame.

Figure 1.13 Besides having an identifying shape, the keyhole bridge may support the frame weight upon pads.

Figure 1.14 Metal saddle bridges were originally designed to rest directly on the crest of the nose. They may occasionally still be used as originally designed shown in the frame pictured. More often a metal saddle bridge is just for decorative purposes and is used in conjunction with nose pads.

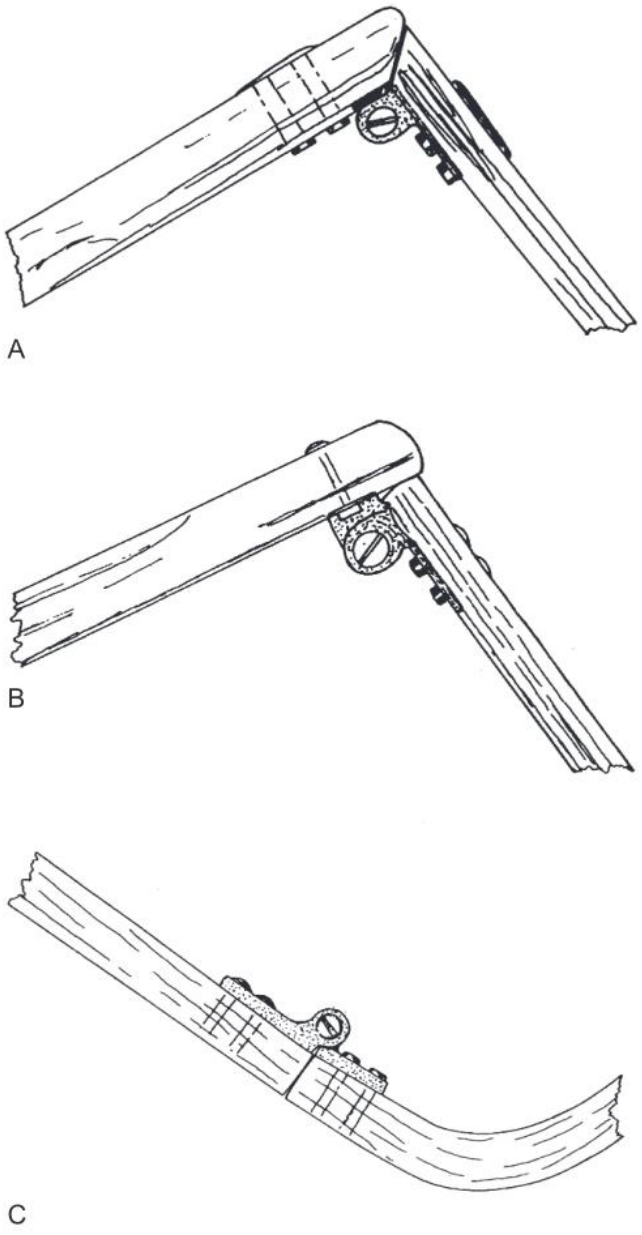

Figure 1.15 Endpieces of plastic frames classified as mitre **(A),** butt **(B),** and turn-back **(C).**

2. *Library temples* used to begin with an average width at the butt and increase in width posteriorly but may take the opposite configuration, beginning wide. The identifying characteristic is that they are practically straight and hold the glasses on primarily by pressure against the side of the head. Thus they are also known as *straight-back temples.*
3. *Convertible temples* were originally designed so they could be bent down to take on the form of skull temples, and "converted" from the straight-back to the skull design. Because this temple is versatile and can be made to fit people with a variety of temple length requirements, it is commonly used. However, it resembles the skull temple in that it comes already bent down for a certain temple fit. If the bend is in the wrong location, the temple may be straightened out and then rebent to fit the wearer.
4. *Riding bow temples* curve around the ear, following the crotch of the ear where the ear and the head meet and extend to the level of the earlobe. Made from plastic, they are sometimes used in children's and safety frames.

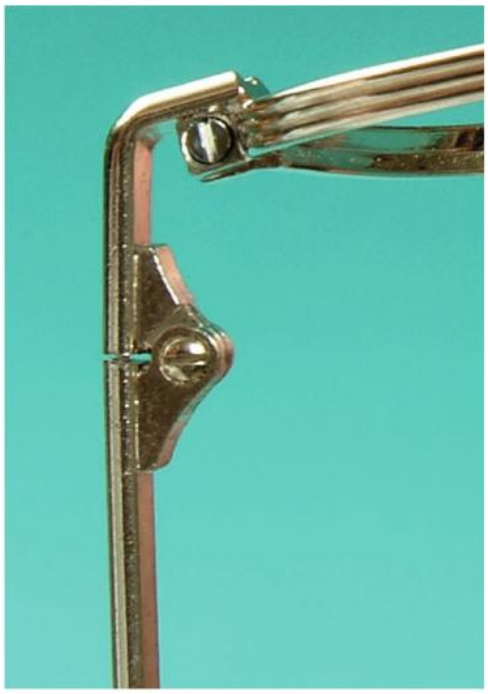

Figure 1.16 This traditional metal endpiece has a turn-back design.

Figure 1.17 Some metal endpieces are not really endpieces at all. The endpiece and temple are one continuous piece of material as in this "wrap" endpiece design.

5. *Comfort cable temples* are shaped the same as riding bow temples but are of metal construction with the *curl*, or behind-the-ear portion, constructed from a flexible coiled cable.

FRAME MATERIALS

Plastic Frame Materials

The first classification of a frame is by the material used in its construction: either plastic or metal.

An early plastic frame material was *cellulose nitrate.* Cellulose nitrate accepts a good polish but is dangerously flammable if brought

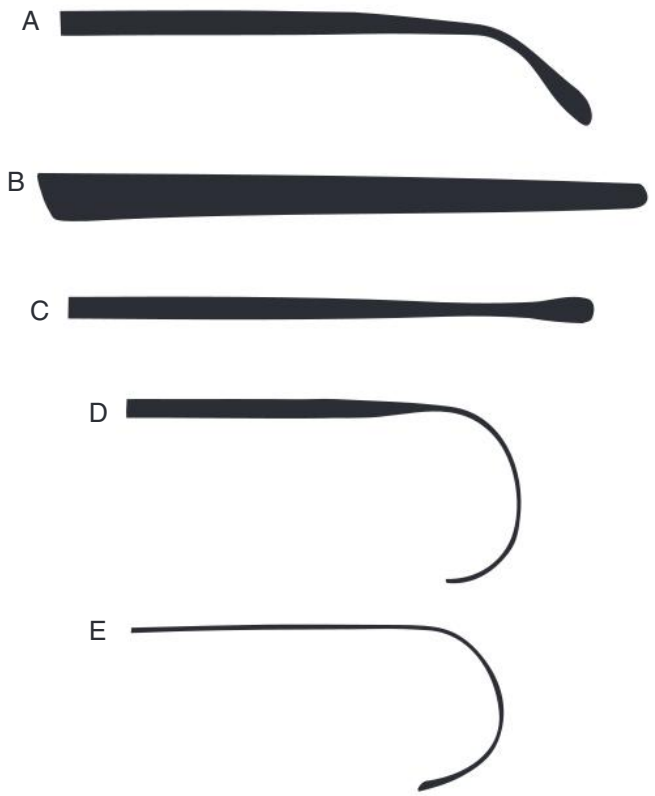

Figure 1.18 Categories of temples are: **A,** Skull; **B,** library; **C,** convertible; **D,** riding bow (in plastic); and **E,** comfort cable (in metal).

to a sufficiently high temperature. Because of the danger, cellulose nitrate was banned and is no longer used for spectacle frames. The most common plastic frame material at the time of this publication is cellulose acetate.

Cellulose Acetate

A material used extensively for spectacle frames is *cellulose acetate*. The basic cellulose material may be extracted from cotton or wood pulp and then further processed.[1] When derived from cotton, the material used is the fiber that adheres to the cottonseed after ginning and is too short to be used for making textiles.[2] In spite of being treated with plasticizers and aging stabilizers, cellulose acetate does become brittle with age.

Some allergies are attributed to wearing cellulose acetate frames, although this is rare. More often skin problems are not so much allergic reactions to the material itself but to those things that can be absorbed by the material. Higher quality cellulose acetate frames are coated to seal the surface. A good frame coating will contain an ultraviolet light inhibitor. This inhibitor in the coating helps to keep frame color from fading.

Cellulose acetate can be formed into sheets of plastic from which frame parts may be cut (Figure 1.19). The manufacturing of cellulose acetate sheets allows considerable creativity in color variations by layering and laminating the sheets.

Cellulose acetate frames are often traditionally referred to as *zyl* (*zylonite*) frames.[3]

When cutting frame fronts and temples from large sheets of cellulose acetate, there is a lot of the acetate sheet material surrounding the cut out frame parts that would otherwise be discarded. To reduce the amount of wasted material, efforts have been made to develop cellulose acetate frame material from discarded acetate and other recycled plastic product. Eastman, one of the largest producers of plastics, has developed a material called Eastman Acetate Renew made from 60% bio-based and 40% recycled product. This is then supplied to companies that make the sheet acetate used by frame manufacturers.[4]

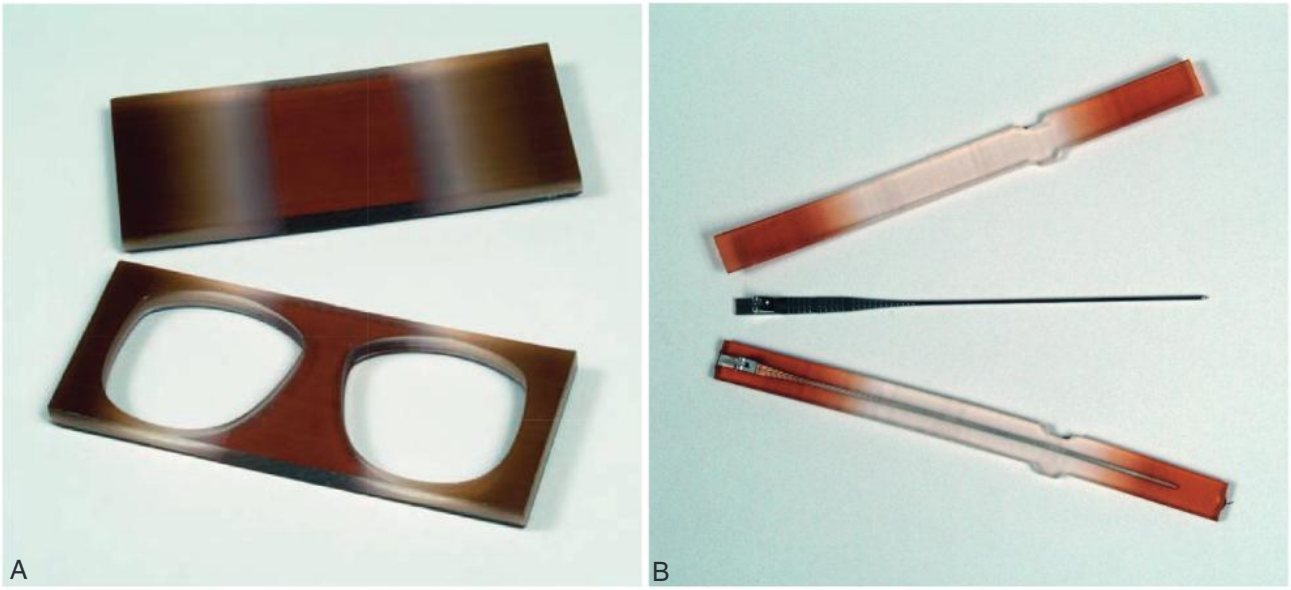

Figure 1.19 Frame fronts and temples are milled from slabs of cellulose acetate. They are finished in steps until being polished and are usually coated to protect the frame material from sunlight and to decrease the possibility of allergic reactions in sensitive wearers. **A,** The frame front is being milled from a slab of plastic. **B,** One method for making temples. First, the cellulose acetate is formed *(top)*. Then, the metal hinge and core *(middle)* is injected into the plastic *(bottom)*. From this point, the temple is milled to the desired form and then shaped.

Nylon-Based Materials

"Pure" nylon was previously used extensively for sports eyewear. Although it had many positive attributes, it was difficult to work with in its pure form. As a result, frame manufacturers began switching to blends that combined nylon with other materials for added strength and stability. As blends, nylons are often used for sports and for sunglass frames.[5] Thus it remains a part of the array of frame materials currently in use.

Propionate. Cellulose aceto-propionate is a nylon-based plastic more commonly referred to simply as *propionate*.[3,6] It has many of the same characteristics as cellulose acetate and works better for injection molding. When using an injection molding process, propionate frames are made beginning with granules of the material that are heated until liquid and then injection molded into the desired frame shape. Granules may initially be colorless, allowing frame parts to then be dyed to the desired color. Propionate has a slight weight advantage over acetate and can also be made thinner.

Polyamide/Copolyamide. Polyamide is a nylon-based material that is quite strong. Because it can be made thinner and is only 72% of the weight of cellulose acetate, polyamide has a real weight advantage. Polyamide frames can be made opaque or translucent. Frames made from polyamide are resistant to chemicals and solvents and are also hypoallergenic.[7] (For more on polyamide frames, see the section in Chapter 7, *Insertion Into a Polyamide Frame.*)

Grilamid. Grilamid is a nylon-based material. It is a subset of polyamide and, because of its strength and durability, it is used in sports and performance eyewear. Unlike plain nylon frame material, grilamid has a large variety of color possibilities.

Trogamid. Trogamid is also a subset of polyamide that gives a transparent quality to frames, has a high chemical resistance, and is durable.[8]

Carbon fiber. Carbon fiber material is used to create a thin, strong frame. This material is made from strands of carbon fibers combined with nylon. It is not adjustable and is consequently used mainly for frame fronts. The temples are generally made from another material. In other words, if a carbon fiber frame does not fit well in frame selection, do not plan on making it fit well later. The principle advantage is the light weight that can be achieved. Carbon fiber is 60% the weight of cellulose acetate. Not only is the material light weight, but, because of its strength, it can also be made thinner. Since carbon is black, frame colors will be opaque and are limited.

Some problems may be encountered with breakage in cold weather. Because of the thermal problems, it is imperative that the material not be directly worked with right after it has been outside. (For more information on working with carbon fiber material, see the section in Chapter 7 on *Insertion Into a Carbon Fiber Frame.*)

Optyl

An epoxy resin used for spectacle frames is known under the trade name of Optyl. A liquid resin and a hardener are mixed together and drawn into the frame molds using a vacuum process. The material is *thermosetting plastic*.[9] That means that it will bend when heated and maintains that shape when cooled. But it will return to its original shape when reheated. Other plastic frame materials such as cellulose acetate and propionate are *thermoplastic*. This means that they will bend when heated and will retain that bend, but they do not return to their original shape when reheated because they do not have a "*plastic memory*."

Optyl is approximately 30% lighter than cellulose acetate.[2] Because of its stability, Optyl is appropriate for those who might be allergic to other types of frame materials. (For more information on working with Optyl material, see the section in Chapter 7 on *Insertion Into an Optyl Frame.*)

Figure 1.20 Safety frames with plano lenses can be molded as one unit. In the sample shown, both the frames and lenses are molded together from polycarbonate material.

Polycarbonate

Polycarbonate is a material usually associated with lenses but can be molded into frames. Frames made from polycarbonate are primarily for sport or safety purposes. When made for nonprescription purposes, the lenses and frame are molded as one unit.

Frames (and lenses) made from polycarbonate are very impact resistant. Unfortunately, polycarbonate frames do not work well for conventional eyeglasses because of their resistance to adjustment. They are better suited for the type of sports glasses that are held in place with elastic straps or for shield types of glasses that may be used either alone or worn over conventional glasses (Figure 1.20). Caution: Polycarbonate is degraded and whitens with acetone.

Combinations of Plastic Materials

There are numerous possible combinations of plastic materials. These include materials sometimes called *memory plastics*. Memory plastics are tough and flexible. They can be bent or twisted and still return to their original shape.

Not all composite plastic materials are memory plastics. Other composite plastics combine various materials to produce frames and frame parts for specific needs and purposes.

Metal Frame Materials

In the first half of the 1900s, gold-containing alloys were the more predominant metals used for spectacle frames. (See Chapter 2, *Gold Classifications for Metal Frames With Substantial Gold Content.*) Today few frames contain any gold.

Great progress has been made in metal frames because of the electrolytic treatment techniques, which allow for corrosion resistance and finished beauty. Any nostalgia over the disappearance of gold alloy frames from the marketplace should be dispelled by the beauty and serviceability of the product that has taken its place.

It is common for frames to be made with more than one material. The temples may be from one material for flexibility, the frame front from another, and the connecting pieces something different still.

This writing does not attempt to include all the material possibilities for ophthalmic frames. There are other materials well suited but less common and others yet to come.

Nickel-Based Materials

Nickel is a material that is often used for eyeglass frames. It is strong and malleable. The main disadvantage is the number of people who

may have an allergic reaction to nickel. It is reported that 10% of the population may be allergic to nickel.[10] Fortunately, high-quality ophthalmic frames are coated with a protective material that both prevents corrosion and keeps the metal from coming in direct contact with the skin while the coating remains on the frame.

Nickel silvers. Nickel silvers contain primarily copper, nickel, and zinc. Percentages may vary with approximately 62% copper, 18% nickel, and 20% zinc.[11] But "nickel silver" contains no silver. Copper gives the material its pliability, zinc adds strength, and nickel gives the alloy a whitish appearance. When the nickel content of nickel silver exceeds 12%, the copper color no longer shows through.[1] Another name for nickel silver is *German silver*.

Monel metal. Monel is whitish in color, is pliable for good adjustment, resists corrosion, and accepts a high polish. It is made from nickel, copper, iron, and traces of other elements. The largest component of the material (63% to 70%) is nickel. The second largest component is copper. Iron constitutes only about 2.5%, and there are traces of silicium (silicon), carbon, and sulfur.[1] Monel is used quite often as a frame material.

Aluminum

Aluminum is both strong and extremely lightweight. It can be finished in a wide variety of colors and does not corrode. Aluminum does not solder or weld well, so it must be made such that its parts are assembled with screws or rivets.[12] It holds the adjustment well but has no flexibility. If it bends, it stays that way.

Stainless Steel

Stainless steel is made mainly from iron and chrome and is highly resistant to corrosion. Stainless steel is strong and can therefore be made thin. When made very thin, it has an element of springiness and flexibility that makes it well suited for temples.[13] Stainless steel is one of the more nonallergenic materials.

Titanium

Titanium is a versatile material that has become increasingly common for use in ophthalmic frames.

Advantages. The *advantages* of titanium include the following:

- Titanium is extremely light in weight. When compared with conventional metal frame materials, titanium is 48% lighter.[14]
- Titanium is very strong, which allows titanium frames to be designed exceedingly thin. Thinness also contributes to still more weight reduction.
- Titanium is very corrosion resistant. This makes titanium an excellent choice for people in hot climates or those working in conditions where they would be perspiring a great deal.
- Titanium is hypoallergenic. It should be noted that titanium is often used in combination with other metals. If the wearer is allergic to another of the metals in the alloy, unless the frame is appropriately coated, allergic reactions could still occur. But when titanium is not mixed with other metals, it is the metal of choice for those with skin allergies related to frame wear. This makes titanium a very attractive frame material for those with skin allergies.
- When used in combination with other metals, titanium allows frames to be made so that they are very flexible. Again, this may increase the possibility of allergic reactions if the frame is uncoated.

Disadvantages. The *disadvantages* of titanium are fewer. These include the following:

- Titanium is hard to solder or weld.
- Because the manufacturing process is more demanding, titanium is more expensive than conventional materials.

Differentiating titanium. The American National Standards Institute adopted some of the standards of the International Organization for Standardization (ISO) for frames.

- *Titanium Spectacle Frame*—ISO 12870:2016 addresses Titanium. Section A.9.5 of the 2016 revision states that for a frame to be designated as a "titanium spectacle frame," each of the principal metal components is made of an alloy containing at least 70% titanium by mass.
- *Pure Titanium Spectacle Frame*—Section A.9.6 of the ISO standard states that for a frame to be designated a "pure titanium spectacle frame," each of the principal metal components is made of an alloy containing at least 90% titanium by mass.

Shape Memory Alloys

Not included with the above titanium material are shape memory frames that may contain titanium. One type of *shape memory alloy* may be applied to an alloy made with 40% to 50% titanium and the rest nickel.[15] Other common memory alloy combinations are copper/aluminum/nickel and copper/zinc/aluminum/nickel.[4] Sometimes simply called *memory metal*, these types of combination materials can be extremely flexible and returns to their original shapes after being twisted or flexed. (It should be noted that there will be other types of metal frame materials that will also function like a "memory metal.")

Other Materials and Alloys

There are other materials that are also suitable for frames, including bronze, magnesium, cobalt, palladium, ruthenium, and beryllium.

As would be expected, there are many different possible combinations of previously listed metals that may be combined to optimize certain desired characteristics. Some have trade names applied especially for a combination used by a given frame manufacturer. As frame designs change, metal alloy combinations will vary to meet these new design demands.

Unique materials used to make frames include wood and animal horn, such a buffalo. These frames are typically handmade, less adjustable, and more expensive.

ALLERGIC REACTIONS TO FRAME MATERIALS

As previously noted, most frame manufacturers will use a coating on their frames to protect the frames and to reduce any possibility of allergic reactions. However, sometimes this is not enough.

To reduce the possibility of a reaction for people who have a history of skin reactions to wearing frames, use frame materials that are known to be hypoallergenic. Here are some that are reported to be hypoallergenic:

- Optyl material
- Polyamide/Copolyamide
- Titanium
- Stainless steel

If a person is already having a reaction to their frame, here are some things that may be done to the frame to reduce allergic reactions:

- Have a clear coat finish applied to a frame. Companies that specialize in frame repairs may offer this service. (Incidentally, some dispensers have tried to just coat the inside of the temples with clear nail polish to solve the problem. Unfortunately, this does not work for very long.)
- Use ultrathin, clear heat-shrink tubing over the temples. Optical shrink tubing is available from optical suppliers of spare parts, pliers, and accessories.

If a person has an allergic reaction to nose pads, there are replacement pads available that will eliminate the problem. These pads are:

- Gold-plated metal nose pads
- Titanium nose pads
- Crystal nose pads

(See also the section in Chapter 10 on *Hypoallergenic Nose Pad Materials.*)

For allergic reactions to metal cable temples, use a temple cover to cover the temple. Temple covers come in plastic, vinyl, and silicone materials. There is also "heat-shrink" tubing sold for this purpose, which reportedly takes care of eliminating allergic reactions. (For more on this see the section in Chapter 10 on *Adding Covers to Cable Temple Earpieces.*)

An additional note on allergies: There is a liquid lens liner sometimes used in the groove of a frame to make a loose lens more secure. This material contains latex and should not be used on frames whose wearers have latex allergies.

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PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. What frame type has a frame front with a metal chassis and plastic top rims?
   a. Semirimless
   b. Rimless
   c. Combination
   d. Balgrip
2. What frame has a metal reinforcing arm behind the lens that goes from drilled mounting holes on nasal and temporal sides of the lens?
   a. Rimless
   b. Semirimless
   c. Balgrip
   d. Nylon cord
3. Which frames are made especially for those persons who normally do not need a correction for distance vision but do need a correction for reading? These frames do not need to be removed when looking at objects in the distance.
   a. Nylon cord
   b. Rimless
   c. Half-eyes
   d. Monel
   e. Combination
4. Which of these eyeglasses do not rest on the nose but are simply hand-held in front of the eyes?
   a. Half-eyes
   b. Lorgnettes
   c. Balgrips
   d. Semirimless
   e. Nylon cord
5. When someone refers to a frame material as *zyl,* they are usually referring to what kind of frame material?
   a. Monel
   b. Propionate
   c. Nylon
   d. Optyl
   e. Cellulose acetate
6. Which type of plastic temple curves around the ear following along the side of the head where the ear and head meet and extending on down to the level of the earlobe? This type of temple may be used for children and sometimes with safety frames.
   a. Library
   b. Skull
   c. Riding bow
   d. Comfort cable
   e. Convertible
7. This frame bridge type follows the bridge of the nose smoothly, spreading the weight of the frame using nose pads that are a part of the back of the frame bridge.
   a. Keyhole bridge
   b. Modified saddle bridge
   c. Saddle bridge
   d. Pad bridge
8. This frame material is made from large sheets of material that is then cut and milled into frame fronts and temples.
   a. Polyamide
   b. Cellulose acetate
   c. Polycarbonate
   d. Propionate
   e. Optyl

9. Frames made from these materials are made beginning with granules heated until liquid and then injection molded to the desired frame shape.
   a. Polyamide
   b. Cellulose acetate
   c. Polycarbonate
   d. Propionate
   e. Optyl
10. This material is made from a liquid resin and a hardener that are mixed together and drawn into the frame molds using a vacuum process.
   a. Nylon
   b. Polyamide
   c. Cellulose acetate
   d. Polycarbonate
   e. Optyl
11. What is the designation given to titanium-containing frames in which all alloy containing components are at least 90% titanium by mass.
   a. Shape memory alloy spectacle frame
   b. Pure titanium spectacle frame
   c. Titanium spectacle frame
12. Which of the following frame materials is not just hard to adjust—it cannot be adjusted at all?
   a. Optyl
   b. Polycarbonate
   c. Cellulose acetate
   d. Aluminum
   e. All of the above are fully adjustable
13. All the following frame materials are said to be hypoallergenic except one. Which one is not hypoallergenic?
   a. Optyl
   b. Polyamide/copolyamide
   c. Titanium
   d. Nickel Silver
   e. Stainless steel

2

Frame Measurements and Markings

THE BOXING SYSTEM

The boxing system uses two horizontal lines—one against the top of the lens and the other against the bottom. There are also two vertical lines. These vertical lines are placed against the right and left edges of the lens. All four lines form a box around the lens (Figure 2.1).

Horizontal Midline

There is a horizontal line halfway between the top and bottom of the lens. In the older datum system, this was called the *datum line.* This name continues to be used. However, in the boxing system, this line is more commonly referred to as the *horizontal midline,* or the *180-degree line.*

Geometric Center

The center of the lens is the point on the horizontal midline halfway between the two lens-bordering vertical lines. It is known as the *geometric center* (GC), or *boxing center*, of the edged lens. This term does not imply anything about the location of the optical center of the lens.

Size

The size of the lens is the length and depth of the box containing the lens. The horizontal length is commonly referred to as the *eye size* when referring to the frame and the *lens size* when referring to the lenses. Both are measured in millimeters.

When most practitioners speak of lens size or eye size, they are referring primarily to the horizontal measure of the lens, denoted by the letter "A" in Figure 2.1. Some frames list an eye size value that is different from and unrelated to the frame A dimension. Such procedures attempt to relate this eye size number to a "fitting value." This is not a recommended practice and leads to confusion but is so commonplace that frame reference materials will usually list both an A dimension and an eye size, even if they are the same value.

The letter "B" denotes the vertical measure of the box enclosing the lens. Both "A" and "B" are, in a sense, independent of lens shape. The letter "C" refers to the width of the lens itself along the horizontal midline.[1] (This can vary considerably from the A dimension.) The C dimension of a lens is seldom used. In the older datum system, this was the eye size of the frame. Some people still mistakenly measure the boxing eye size this way.

The C dimension of a lens should not be confused with the "C-size" of a lens. *C-size* is the circumference of the edged lens and is used to increase accuracy when duplicating an old lens size when edging. When tracing the inside of a frame shape with a frame tracer to guide a lens edger, the tracer uses the C-size of the frame shape for greater accuracy in edging.

Measurement

In determining the horizontal boxing dimensions of a *frame*, the measurement begins at the inside of the groove on the left side of the imaginary enclosing box and extends horizontally across the lens opening to the farthest part of the groove on the right side of the box (Figure 2.2). Do not tilt the box.

In measuring a *lens*, the measurement begins at the apex, or point, of the bevel on the left side of the box enclosing the lens and extends to the apex of the bevel on the right side of the box. Remember, the A dimension is the width of the enclosing box. It is not the width of the lens at the middle of the shape.

Effective Diameter

The effective diameter (ED) of a lens is found by doubling the distance from the GC of the lens to the apex of the lens bevel farthest from it. This is called the *longest radius* (see Figure 2.1). This measurement helps to determine the smallest lens blank from which the lens can be cut (see Chapter 5: Determining Lens Blank Size).

Note: An extremely common mistake made in measuring the ED of a lens or frame shape is to measure the longest diagonal of the shape. This is done because measuring this way is much easier. However, measuring the ED on the longest diagonal is wrong! Sometimes this erroneous measurement will be close to the actual ED, but it is not the real ED. Measuring the longest diagonal across a lens or frame shape can result in an answer that is substantially wrong.

Frame Difference

The difference between the horizontal and the vertical measurements is known as the *frame difference* and is measured in millimeters. The greater the frame difference, the narrower the shape appears vertically (Figure 2.3). This seems counterintuitive. One would think that a large frame difference would have a comparatively large vertical depth. However, just the opposite is true. Frame difference is sometimes referred to as *lens difference.*

Distance Between Lenses (DBL) or Bridge Size

The boxing system also makes it possible to define the *distance between lenses (DBL).* The DBL is the distance between the two boxes when both lenses are boxed off in the frame. This is usually synonymous with bridge size, although it is important to note that manufacturers not adhering to the boxing system may mark a bridge size that does not correspond to the DBL.

Bridge size, or DBL, is measured on the frame as the distance from the inside nasal eyewire grooves across the bridge area at the narrowest point (Figure 2.4). This distance is measured in millimeters. Naturally,

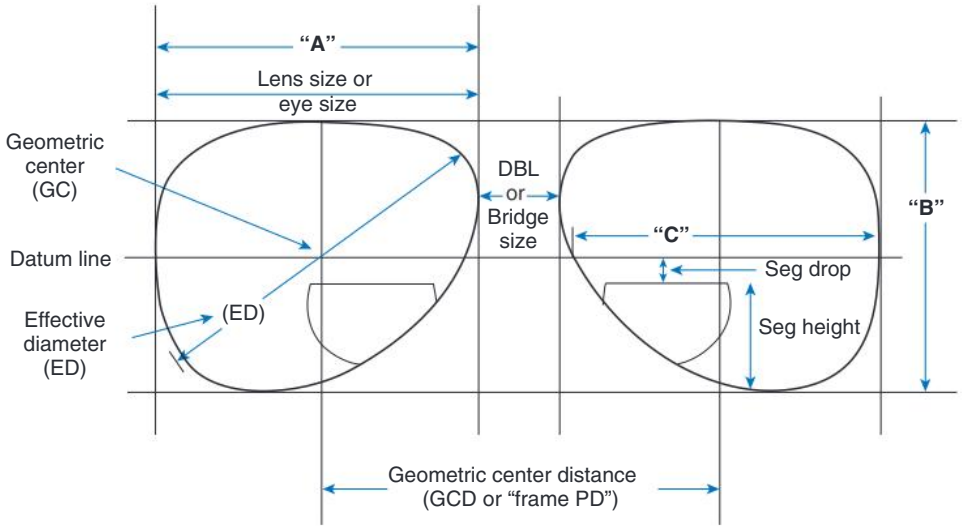

Figure 2.1 In the boxing system, the *A* dimension is the horizontal boxing width. If the frame is marked according to the boxing system, the eye size will be equal to the *A* dimension of the frame. The *B* dimension is the vertical boxing height. The *C* dimension is the width of the lens along the horizontal midline. (This dimension is seldom used today.) The *C* dimension should not be confused with the "C-size" of a lens. The C-size of a lens is the distance around the lens (i.e., its circumference). The C-size ensures that a lens ordered by itself (without the frame) will be exactly sized for that frame. *DBL,* Distance between lenses; frame *PD,* interpupillary distance.

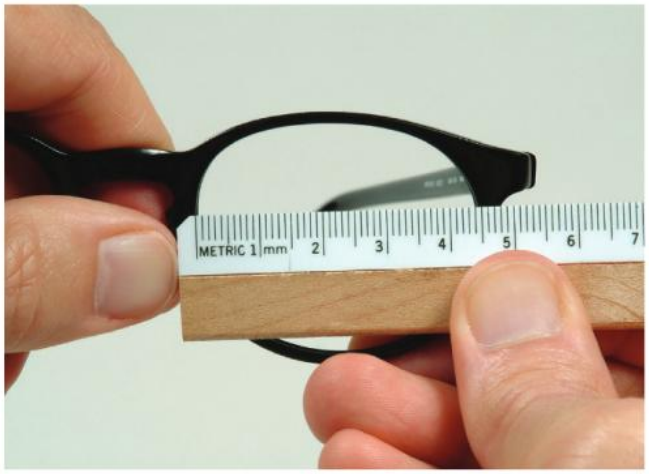

Figure 2.2 To measure the horizontal dimension of a frame, the measurement begins at the inside of the groove on one side and extends horizontally across the lens opening to the farthest part of the groove on the other side. We cannot see the inside of the groove when looking from the front. This means we can estimate where it will be and hold the ruler so that the zero point is at the position of the left-hand side of the groove. Then we need to read the ruler at the position where the groove will be on the right. If the opening itself is measured on a plastic frame, then about ½ mm per side needs to be added to the measure to allow for the depth of the groove. This may vary, depending upon the depth of the groove.

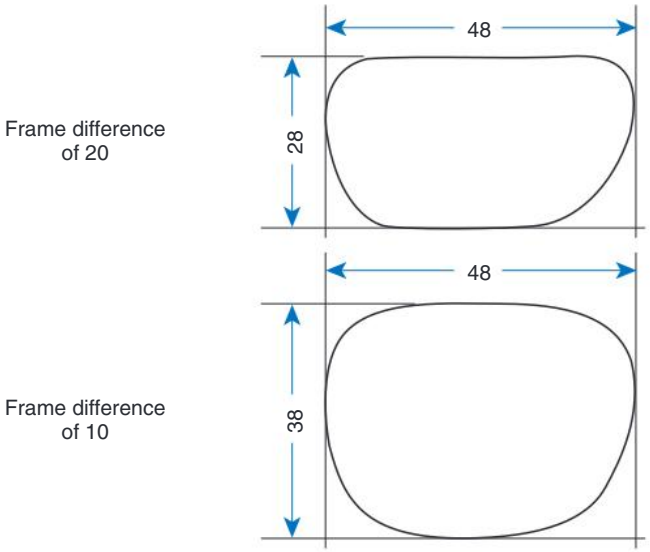

Figure 2.3 The difference between the horizontal and vertical measurements of a frame is known as the *frame difference*.

two frames having the same DBL will not necessarily fit the same person in the same manner because of variations in lens shapes.

Geometric Center Distance (GCD)

The distance between the two GCs of the lenses is known as the *geometric center distance (GCD).* It can be measured more easily as the distance from the far left side of one lens opening to the far left side of the other (i.e., from the left side of one "box" to the left side of the other "box"), or it can be calculated by simply adding the eye size to the DBL; the result is the same.

The GCD is also known by three other names:

1. *Distance between centers*
2. *Frame center distance*
3. *Frame PD*

The term *frame PD* is commonly used in dispensing but has no relationship to the wearer's interpupillary distance, or the distance between pupil centers.

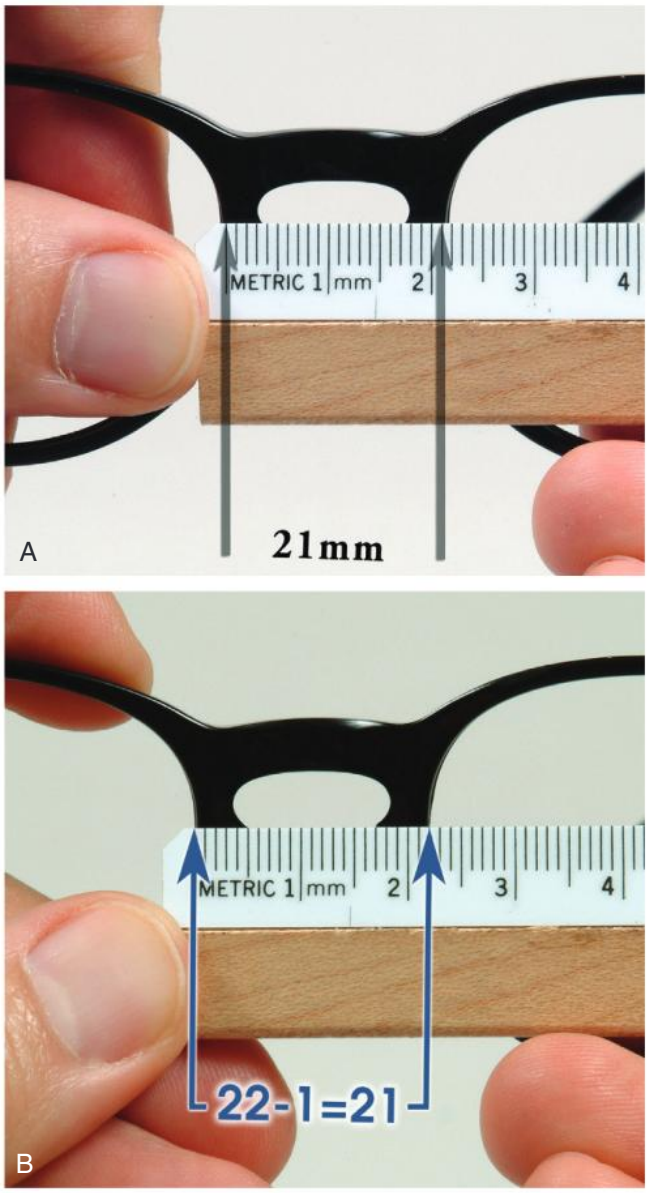

Figure 2.4 **A,** The distance between lenses, or bridge size, is measured on the frame as the distance from the inside nasal eyewire grooves across the bridge area at its narrowest point. When measuring the bridge size, we cannot see the inside of the groove and must estimate its location. **B,** If the measurement is made from lens opening to lens opening, then approximately ½ mm per groove must be *subtracted* from the measure, depending upon the depth of the groove.

Segment, or Seg, Height

When specifying bifocal or trifocal segment height, the reference points are given in millimeters as either:

1. the distance below or above the horizontal midline (called *seg drop* or *seg raise*) or
2. the distance from the lower line of the boxing system rectangle enclosing the lens shape (called *seg height*).

In the actual measuring process, the level of the lower line of the box corresponds to the lowest point in the eyewire groove. *This level may be different from the depth of the point on the lens edge found directly below the pupil* as can be seen by looking carefully at Figure 2.1.

Fitting Cross Heights for Progressive Addition Lenses

Bifocals provide additional lens power for near vision and have near segments for near viewing. These segments have lines that are used as references when vertically positioning the lenses. Unlike a bifocal lens, the near viewing area of a progressive addition lens does not have a visible line. With the frame adjusted to fit the wearer, the dispenser marks horizontal lines on the frame's demonstration lenses at the locations of the centers of the wearer's pupils. Also a vertical line through the center of the wearer's pupil will form a cross used for fitting the progressive addition lens. The vertical height measured from the lowest level of the inside bevel of the eyewire to the marked horizontal line is called the *fitting cross height.* (Many dispensers and even optical labs call this the *seg height* of a progressive lens instead of the *fitting cross height*. This is because of the similarity in manner of measurement to a bifocal even though the bifocal segment height is measured to the lower lid margin and not the pupil center.)

OVERALL TEMPLE LENGTH

Most temples are currently marked with the total, or overall, temple length. Temple lengths are expressed in millimeters. The overall temple length is the distance from the center of the barrel screw hole to the posterior end of the temple measured along the center of the temple (Figure 2.5). Many times the center of the barrel screw hole will also correspond to the position of the butt end of the temple, although this is not always the case. When measuring the overall temple length, it is necessary to measure around the bend and not in a straight line unless, of course, the temple is straight. The easiest way to do this is shown in Figure 2.6, *A* through *C*.

Comfort cable temples are measured in terms of overall length. The actual measurement is done by grasping the tip and extending the temple along the ruler (Figure 2.7).

FRAME MARKINGS

Most frames are marked according to size with three measurements: eye size, DBL, and temple length. Metal frames that are manufactured from "rolled gold" are also marked as to the amount of gold found in the frame. Rolled gold frames were used regularly many years ago. Any new rolled gold frames are rare and very expensive.

Eye Size, DBL, and Temple Length

When a frame marking such as 50□20 is seen, it means that the eye size is 50 mm and the DBL is 20 mm. The box between the numbers means that the eye size is measured according to the boxing method; it also serves to separate the two numbers and prevent confusion. The eye size and DBL are sometimes simply marked 50 20, 50-20, or 50/20.

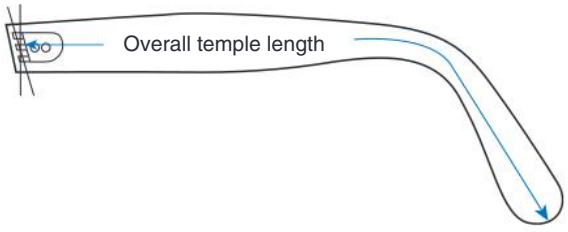

Figure 2.5 Temple length is measured from the center of the hinge barrel to the end of the temple.

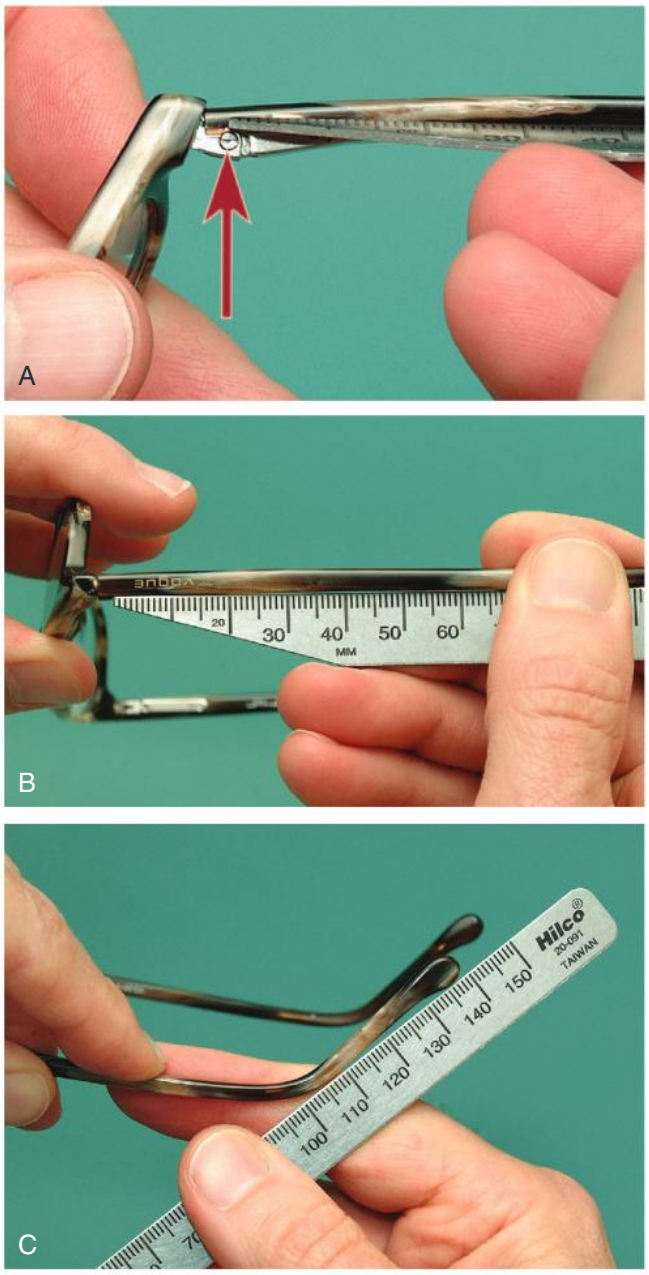

Figure 2.6 Measuring overall temple length. **A,** Begin the measurement by placing the zero on the ruler at the center of the hinge barrel. **B,** Looking at the temple from the side, it is evident that the zero point is not at the butt end of the temple. Often the position of the center of the barrel and the butt end of the temple are at the same location. It is obvious from the photo that in this case they are not, and, thus, the beginning point for measuring does not start at the end of the temple. **C,** Rotate the ruler around the temple bend and note where the end of the temple falls on the ruler scale. This is the overall temple length.

The temple length is a three-digit number and is typically manufactured, measured, and marked in 5 -mm increments.

Location of Markings

On a *plastic frame* the marking may be found in any of several places. It may be printed on the inside of a modified saddle bridge nose pad, or it may be found on the upper outer section of the eyewire. Sometimes the eye size is printed on one endpiece and the DBL on the other. As it should be, temple length is printed on the inner side of the temples. It is common practice to put all three measurements on the temple. This is done because frames are sold as a complete unit rather than a frame front with a matching set of temples.

Figure 2.7 The overall temple length for a cable temple is obtained by stretching the cable temple along the ruler.

On *metal frames* and frames with metal chassis, the eye size and DBL are commonly printed on the temple, as they are with plastic frames. However, size might be found on the inside of the bridge, or it is occasionally printed on the underside of a top reinforcing bar.

Frame Manufacturer Name, Color, Country of Origin, and Frame Name

Frames should also be marked as to the manufacturer name, color, country of origin, and frame name. Many frame manufacturers use a number as a name. This can be confusing as the frame color may also be specified by number, with both numbers stamped on the frame. Consulting a frame reference database or catalog will help.

Safety Frame Markings

Frames that are suitable for use as prescription safety glasses will have "Z87-2" and the name or logo of the manufacturer stamped on the frame front and on both temples. This is as specified by the American National Standards Institute (ANSI) in their standard called *American National Standard Practice for Occupational and Educational Eye and Face Protection.* The standard is numbered as Z87.1. Even if a pair of prescription eyeglasses has safety lenses, if it is not in a frame marked "Z87-2," the glasses are not safety glasses. (For more on safety eyewear, see Chapter 23.)

Gold Classifications for Metal Frames With Gold Content

Currently, almost no metal frames have any gold content. This does not imply anything about the quality of the frame, since current manufacturing can result in both beautiful and often allergy-free metal frames without using any gold. (See Chapter 1 for more on frame materials.) However, when a frame has a substantial gold content, numbers other than those indicating the size of the frame are printed on the frame to indicate the nature of the gold content. Gold or part-gold articles can be classified as fine gold, solid gold, gold filled, or having gold plating or gold flashing (Table 2.1).

TABLE 2.1 Gold Classifications

Name	Meaning
Fine gold	100% pure gold
Solid gold	Gold and base metal evenly mixed together Solid gold is marked with a karat system that shows the amount of gold by weight in the gold alloy in comparison to a total of 24 possible weight units. For example, an article or part marked "12k" indicates that 12 parts out of a possible 24 parts are gold; that is, 50% gold by weight
Gold filled	Base metal inside a "solid gold" coating
Gold plating	A base metal thinly plated with gold
Gold flashing	A base metal with gold thinly and quickly applied in a manner similar to that of gold plating

The color of a frame with gold content has nothing to do with its quality. The color depends on what type of metal is used in combination with gold to make the gold alloy.

As with jewelry, the karat system is used to determine the amount of gold present. The number marked on the article is the amount of gold by weight in comparison to a total of 24 units: an article marked 12k is an alloy made up of one-half gold and one-half another metal.

REFERENCE

1. Fry G. The boxing system of lens and frame measurement, part IV. *Optical J Rev Optom.* 1961;98(17):32–38.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. In the boxing system, the effective diameter is the diagonal of the box.
   a. True
   b. False
2. The frame difference for a frame with a circular lens shape is always zero.
   a. True
   b. False
3. Which of the following is NOT the same as the geometric center distance?
   a. the eye size (A) plus the bridge size (DBL)
   b. the wearer's PD
   c. the frame PD
4. A frame has the following dimensions:
   A = 51
   B = 47
   DBL = 19
   Seg drop (distance below the horizontal midline) is 4 mm.
   What is the seg height?
   a. 19.5 mm
   b. 20 mm
   c. 21.5 mm
   d. 23.5 mm
   e. none of the above
5. Which lens shape has the largest frame (or lens) difference?
   a. A round shape
   b. A square shape
   c. A lens shaped like a vertically narrow rectangle (the vertical dimension is considerably smaller than the horizontal dimension)
   d. A lens shaped like a vertically deep rectangle (the vertical dimension is only slightly smaller than the horizontal dimension)
6. If a frame has an A dimension of 50 and a frame difference of 8, what is its B dimension?
   a. 58 mm
   b. 56 mm
   c. 52 mm
   d. 46 mm
   e. 42 mm
7. If a frame has the following dimensions, what is the "frame difference"?
   A = 47
   B = 30
   DBL = 19
   ED = 49
   a. 1.5 mm
   b. 2 mm
   c. 17 mm
   d. 18 mm
   e. 20 mm
8. The ED (effective diameter) of a frame is which of the following?
   a. Two times the longest radius
   b. Vertical boxing dimension
   c. A + DBL
   d. Eye size
   e. The C dimension
9. A frame is marked 52□18. The lens shape is round. What is the effective diameter of the lens?
   a. 70 mm
   b. 61 mm
   c. 58 mm
   d. 52 mm
   e. 18 mm
10. What is the geometric center distance of a frame marked 52□17?
    a. 52
    b. 60.5
    c. 69
    d. 72
    e. equal to the person's PD

11. If a lens has a horizontally oriented oval shape, the ED will be…
- **a.** greater than the A dimension of the frame
- **b.** the same as the A dimension of the frame
- **c.** less than the A dimension of the frame
- **d.** impossible to know from the information given

12. If a lens is exactly square, the ED is…
- **a.** greater than the A dimension of the frame
- **b.** the same as the A dimension of the frame
- **c.** less than the A dimension of the frame
- **d.** impossible to know from the information given

13. The color of a frame containing the metal gold will depend upon…
- **a.** the quality of gold used.
- **b.** the quantity of gold used.
- **c.** the kind of metal combined with the gold to make the alloy.
- **d.** None of the above are correct responses.

14. What is the name used for an article that has no metal in it other than chemically pure gold?
- **a.** Fine gold
- **b.** Gold filled
- **c.** Gold plated

15. Safety frames must be marked with…
- **a.** the manufacturer's name on both temples and frame front.
- **b.** "Z80-2" on both temples and frame front.
- **c.** "Z87-2" on both temples and frame front.
- **d.** The manufacturer's name or logo and "Z80-2" on both temples and frame front.
- **e.** Each major part of a safety frame must be marked Z87-2, plus the manufacturer's name or logo. The American National Standards Institute (ANSI) standard for safety frames is designated by the code Z87.

3

Measuring the Interpupillary Distance

DEFINITION

The distance between right and left pupils is called either the *pupillary distance* or the *interpupillary distance* and is often abbreviated as *PD*. The *anatomic PD* is the distance from the center of one pupil to the center of the other pupil measured in millimeters. Before ordering prescription glasses or even before doing a refractive visual examination, the distance between the pupils must be determined. It can be measured in a variety of ways.

DISTANCE PD

Binocular PD

The most basic method used to measure the PD also requires the least amount of equipment. The technique uses a simple millimeter ruler, commonly referred to as a *PD ruler*.

Technique

When the PD is to be measured, the dispenser should be positioned at a distance of 40 cm (16 inches) directly in front of the subject, with his or her eyes at the same vertical level as those of the subject. The PD ruler is positioned across the subject's nose with the measuring edge tilted back so that it rests on the most recessed part of the nose. The dispenser holds the PD ruler between the thumb and forefinger and steadies the hand by placing the remaining three fingers against the subject's head.

The dispenser closes the right eye and sights with the left (Figure 3.1). The subject is instructed to look at the dispenser's open eye while the dispenser lines up the zero mark of the ruler with the center of the subject's pupil.

When the zero mark is lined up correctly, the dispenser closes the left eye and opens the right. The subject is instructed to look at the dispenser's open eye. The PD for the distance prescription is read off as that mark falling in the center of the subject's left pupil (Figure 3.2).

The dispenser now closes the right eye and opens the left. The subject is again instructed to look at the dispenser's open eye. This step is primarily a recheck to make sure the zero mark is still properly aligned. (This technique is summarized in Box 3.1.)

When difficulty is experienced in determining the exact center of the pupil, the edge of the pupil may be used as a measuring point if both pupils are the same size. Measurement is read from the left side of one pupil to the left side of the other. (Note: Measuring from the inside edge of one pupil to the inside edge of the other or from the outside edge of one pupil to the outside edge of the other is incorrect and results in large errors.)

When a person has dark irises or unequally sized pupils, it may be difficult to use either the center or the edge of the pupil. In these cases, the dispenser may use the limbus edge—the sharp demarcation between white sclera and dark iris (Figure 3.3). Because the pupil is displaced 0.3 mm nasalward from the center of the limbal ring,[1] a limbal measure will be approximately 0.5 mm greater than the measure found using pupil centers. In other words, subtract 1/2 mm from what was measured. Remember, the same sides of the limbus (both left or both right) must be used, or an extremely large error is induced.

Common Difficulties and Their Solutions

Dispenser cannot close one eye. Occasionally, the person doing the measuring is unable to close one eye independent of the other. This is solved by covering one eye with the free hand. Holding the lid down with one finger gives an unprofessional appearance, especially when wearing glasses. Covering one eye with the hand held flat appears to be a natural part of the test and does not reveal a person's inability to close only one eye.

Dispenser visually impaired in one eye. If the dispenser is blind in one eye or has visual acuity too poor to allow the ruler to be read accurately, then the technique is modified. The dispenser places the good eye directly in front of the subject's right eye and at the normal distance. The zero mark is lined up as usual. The dispenser then moves sideways until the good eye is positioned in front of the subject's left eye and the measurement is read. Unfortunately, this method can easily lead to parallax errors. The most desirable solution for someone with this difficulty is to use another type of instrument that only requires the use of one eye.

Subject is strabismic. The strabismic subject, with one eye pointing in a different direction from the other, presents a special problem. The PD ruler method of measurement may then give an artificially high or low reading. To determine a true reading, simply cover the subject's eye not being observed. This ensures that the subject is fixating with the eye under observation and is not turned unless eccentric fixation is present. (Even if eccentric fixation is present, the PD measurement is still correct, since the subject never uses this eye in any other position relative to the dominant eye.)

In some instances in which one eye turns out constantly, the prescribing doctor may determine that the wearer is better served if the lenses are centered in front of the pupils, even for the eye that is turned. This will require that a separate measure be taken for each eye. One measurement will then be considerably larger than the other.

An uncooperative child. If the subject is young or uncooperative, making normal PD measurements impossible, the dispenser may have to take a canthus-to-canthus measurement. (The canthus is the corner of the eye where the upper and lower lids meet.) This is done by measuring from the outer canthus of one eye to the inner canthus of the other eye. Unfortunately, this measurement is not entirely exact, since the inner canthi of the eyes encroach farther across the sclera with younger children than the outer canthi.

Common Causes of Errors

There are several common causes of errors inherent in using a PD ruler.[2]

1. The measurer's PD differs significantly from the subject's PD. This means the lines of sight are not parallel. For example, if the measurer's PD is 16 mm larger than the subject's, the reading will be 1 mm too large because of this parallax error.
2. The PD ruler is not tilted back so that the scale is in the most recessed part of the bridge of the nose. This will correspond to

the approximate position where the spectacles will be worn. If the ruler is too far away from the eyes, a parallax error can occur.
3. Just as error will be increased when the measurer's PD is significantly different from the subject's, the parallactic error will also be increased even more if the dispenser is too close to the subject. Too close is closer than the normal 40 -cm (16-inch) distance.
4. One eye turns outward or inward when the person is not concentrating. A significant error will be induced if the subject is not fixating binocularly during the PD measurement. What does "not fixating binocularly" mean? In simple terms, the person will only be using one eye to see instead of both eyes. When this does happen, most of the time the direction will be outward. When one eye turns outward, the measurement is then too large.
5. An error can result if the subject's head moves his or her head.
6. An error will result if the person measuring does not close or occlude one eye at a time to ensure sighting from directly in front of the subject's eye under observation.
7. The subject may not look directly at the dispenser's pupil during the test.

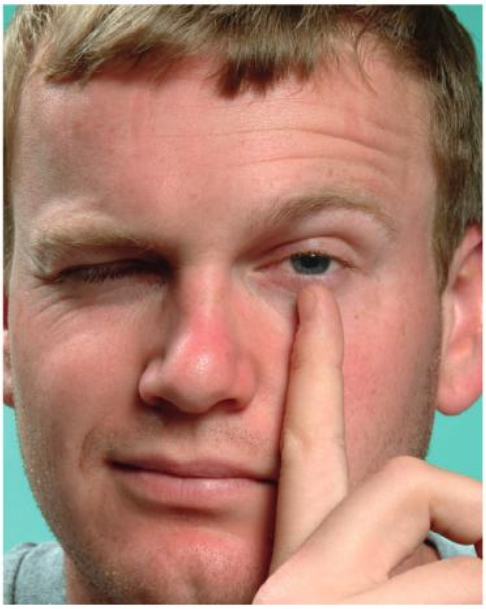

Figure 3.1 Position of the dispenser for beginning the interpupillary distance (PD) measurement using just a PD ruler.

Monocular PD

Since faces are not always symmetrical, it is usually better to specify the PD for each eye independently. The main goal in taking the PD is to place the optical centers of the lenses directly in front of the subject's eyes to prevent any undesired prismatic effect.

If one eye is set closer to a person's nose than is the other and the optical centers of the lenses are placed symmetrically in the frame, the wearer's lines of sight will not pass through the optical centers of the lenses. The error is not too serious if the lenses are of the same power and are not strong. If, however, one lens is very different from the other, the centers must be placed accurately to prevent unwanted binocular prismatic effects (Figure 3.4). Monocular PDs are also important when using aspheric lenses or high-index lenses, including polycarbonate lenses. High-index lenses have more chromatic aberration than crown glass or regular (CR-39) plastic lenses. The negative effect of chromatic aberration on vision is increased if the eye is not looking through the optical center of the lens. (For more information on high-index lenses, see Chapter 23. For more information on aspheric lenses, see Chapter 18.) When measuring for progressive addition lenses, monocular PDs are essential. Each eye must track down a narrow corridor to see clearly at intermediate and near distances.

Procedure for Measuring Monocular PDs Using a Ruler

The monocular PD is best taken using a pupillometer. When a pupillometer is not available, monocular PDs are taken by measuring from

BOX 3.1 Steps in Measuring the PD

1. Dispenser positions at 40 cm (16 inches).
2. Dispenser closes right eye, subject fixates on dispenser's left eye.
3. Dispenser lines up zero point on subject's right eye at the pupil center, left pupillary border, or left limbus.
4. Dispenser closes left eye, opens right eye; subject fixates right eye.
5. Dispenser reads off scale directly in line with left pupil center, left pupillary border, or left limbus.
6. Dispenser closes right eye, opens left eye; subject fixates left eye.
7. Dispenser checks to make sure zero point is still correct.

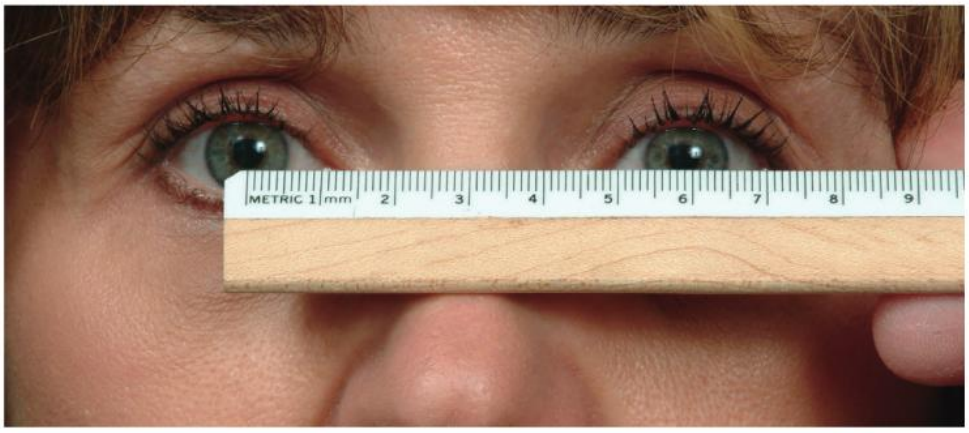

Figure 3.2 The dispenser uses his or her left eye to establish the zero point of the interpupillary distance (PD) ruler in the center of the pupil of the subject's right eye as shown here. The subject is looking at the dispenser's left eye as is shown here. Next, the subject looks at the dispenser's right eye. The dispenser uses his or her right eye to read the PD at the center of the subject's left eye. (This is not what is seen in this photo.)

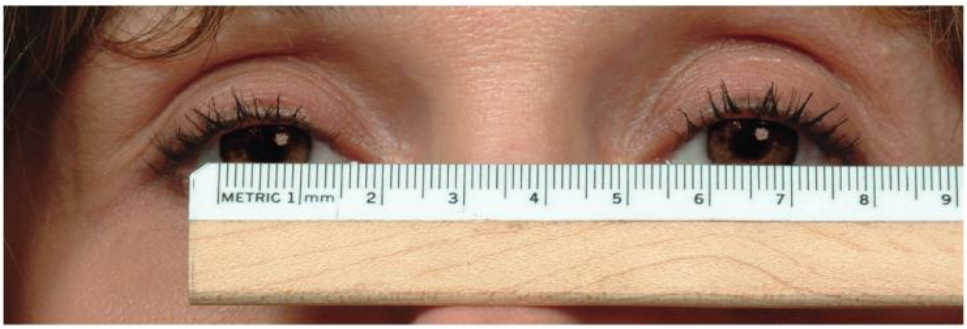

Figure 3.3 When the subject has dark irises, the outside edge of the limbus may be used as the zero-reference point and the inside limbal edge of the other eye as the measuring point.

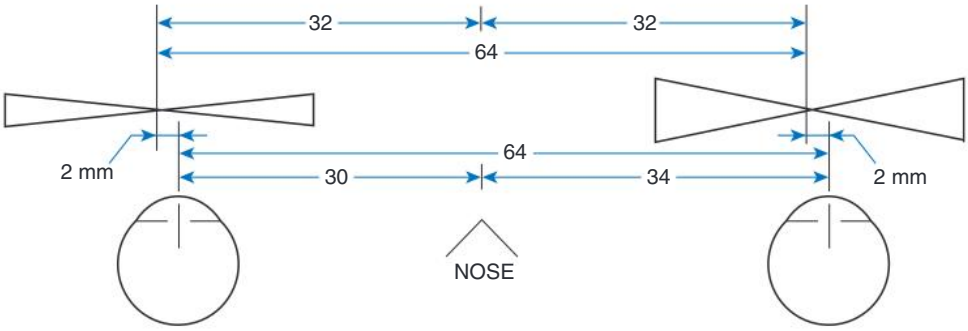

Figure 3.4 Here the interpupillary distance (PD) has been measured binocularly as shown on the top measurements. However, the wearer has very different monocular PDs. Even though the distance PD is 64 mm, the monocular PDs are not 32 and 32 mm. Instead they are 30 and 34 mm. When the lenses are made as if the wearer had 32/32 monocular PDs, in this case there will be unintended Base Out prism caused by the misplaced lenses.

the center of the nose to the center of the pupils. The procedure consists of the following three steps:

1. Measure the binocular PD as described earlier in the chapter. Use the center of the pupil as the reference point.
2. Before moving the ruler, note the scale reading on the ruler at the center of the nose. This is the right monocular PD.
3. Subtract this reading from the binocular reading to obtain the left monocular PD.

For example, the binocular PD is 66. The scale reading at the center of the nose is 32. The monocular PD for the right eye is then 32. To calculate the monocular PD for the left eye, subtract 32 from 66 to get a reading of 34. The procedure is the same as in taking a binocular PD measurement except that the two readings are independent of one another and, for purposes of measuring, the center of the pupil is always used. (There are other methods that are considerably more dependable than measuring with a PD ruler in their ability to yield consistently accurate results.)

Procedure for Measuring Monocular PDs Using the Frame

One error inherent in using a ruler alone appears when a person has an asymmetrical nose. An asymmetrical nose often occurs when a nose has been broken. In this case, the frame positions itself somewhat to the left or right. For the lenses to be accurately placed, this factor must be considered. It is possible to use a marking pen and the demo lenses in the sample frame. (If the sample frame does not have lenses, clear tape may be placed over the lens opening of the empty frame.)

The procedure for measuring monocular PDs begins by adjusting the frame. The frame should occupy the exact position it will have with the lenses in place. The dispenser should be at the same level as the wearer and approximately 40 cm away. The dispenser closes the right eye. The wearer is instructed to look at the dispenser's open left eye. Since there is no ruler used, the dispenser uses a marking pen and marks a cross on the right lens at the location of the center of the wearer's right pupil (Figure 3.5).

Next the dispenser closes the left eye and opens the right eye. The wearer is instructed to look at the dispenser's open eye. The dispenser then marks a cross on the lens directly over the left pupil center.

Because of the movement involved in marking pupil centers and the ease with which unintentional head movement can occur, it is important that these markings be carefully rechecked.

When the dispenser is confident that pupil centers are accurately marked, the frame is removed and the distances from the center of the bridge to the center of each cross are measured and recorded. (These steps are summarized in Box 3.2.)

PD Measuring Instruments

The PD is most easily measured by using an instrument especially designed for this purpose. Readings taken using this instrument are not nearly as subject to parallax errors as those taken using a PD ruler. Such a device also solves the problems caused when the person doing the measuring can only see in one eye or has amblyopia that reduces vision in one eye.

These instruments have an occlusion system, which allows for individual monocular measurements, with each eye fixating alternately in cases of strabismus.

Figure 3.5 To measure monocular interpupillary distances using a marking pen and a frame with lenses in the frame, the same procedure is followed as would be used with a ruler. It is essential that the wearer be looking at the dispenser's eye that is directly in front of the eye being measured. In other words, to mark the location of the wearer's right pupil center, the wearer looks at the dispenser's open left eye. (The dispenser's right eye is closed.) To mark the location of the wearer's left pupil center as shown here, the wearer looks at the dispenser's open right eye. (The dispenser's left eye is closed.)

BOX 3.2 Steps in Measuring Monocular Interpupillary Distances Using the Sample Frame

1. The selected frame is adjusted in exactly the same manner as it will be when worn.
2. Dispenser positions at 40 cm from the wearer and at the same level.
3. Dispenser opens left eye, closes right eye, and instructs wearer to look at dispenser's open (left) eye.
4. Dispenser marks location of wearer's right pupil center on glazed lens.
5. Dispenser opens right eye, closes left eye, and instructs wearer to look at dispenser's open (right) eye.
6. Dispenser marks location of wearer's left pupil center on glazed lens.
7. Dispenser rechecks the locations of the marked crosses by repeating steps 3 and 5 and notes the positions of the marked crosses.
8. If one or both crosses are wrong, the frames are taken off the wearer and the cross(es) removed.
9. When crosses are accurate, monocular interpupillary distances are measured from frame center to cross center.

A well-designed PD-measuring instrument should rest against the bridge of the subject's nose exactly as a frame would. This most accurately approximates the way the glasses will position themselves. It should also position the measuring plane at the approximate spectacle plane.

The subject will see a ring of white, black, or colored light around a central black or white dot within the instrument. The dispenser will see the subject's eye and a scale appearing on it from which a direct measure is read. Alternately, in some instruments, a split image of the pupil may be seen.

Instruments Using Corneal Reflexes

Although some instruments use a method of taking the PD in which the reference point is the geometric center of the pupil itself, a popular alternate corneal-reflex method is used in instruments such as the Essilor pupillometer (Figure 3.6) or the Topcon PD-5, PD Meter. The instruments are supported with pads positioned so that the instrument rests on the nose where the average frame would rest. This is superior to a forehead support system used alone.

The dispenser asks the subject to hold his or her end of the pupillometer so that the pads rest on the nose (Figure 3.7). The forehead support should be against the forehead. The dispenser uses one eye to look into the instrument. (This is a real advantage for dispensers with good vision in only one eye.)

Figure 3.6 The digital version of Essilor's pupillometer displays monocular interpupillary distances (PDs) for the right and left eyes, as well as the binocular PD. It can be set to measure distance or near PDs.

An internal light produces an image by reflection on each cornea, and the hairline within the device is moved until coincident with this corneal reflection (Figure 3.8). The measurement is assumed to correspond with the subject's line of sight, but it is an objective measurement of the position of the corneal reflection rather than the position of the line of sight. In addition to a distance PD, near PD may be measured for near points from 30 or 35 cm to infinity.

The line of sight is defined as a line passing from the center of the pupil to the object of regard. This is the line that desirably passes through the optical center of the lenses and is the basis upon which the measurement of PD rests.

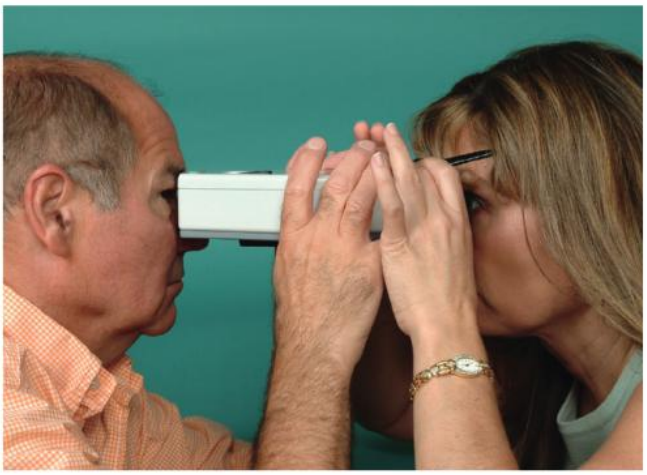

Figure 3.7 To use a pupillometer, the subject (on the right) holds the pupillometer so that the pads rest on the nose in the manner of normal eyeglasses. The dispenser views the subject's eyes through the instrument.

Figure 3.8 The corneal reflection as seen through Essilor's pupillometer. The hair line is adjusted to the center of the corneal reflex. (Courtesy of Essilor, Inc.)

Corneal reflections are observed along a line that intersects perpendicularly the center of curvature of the anterior surface of the cornea. (This line is referred to as the *pupillary axis*.) This line intersects the line of sight at the entrance pupil of the eye and places the corneal reflection somewhat towards the nose. Thus, a PD determined based on corneal reflections will vary slightly from that determined by the centers of the pupils.

It is possible to use a corneal reflection–style instrument to measure a PD based on pupil center distances. To do this, the hairline within the device is moved to the center of the pupil rather than the center of the corneal reflection. The corneal reflection method is the method of choice when measuring a PD for someone with pupils dilated from a recent eye examination.

Using a Tablet-Based System for Measuring PD

There are numerous possibilities for determining PD and other lens-related measurements using a tablet or an iPad. Quite a few lens and lens-related companies have their own systems to assure good results. In addition to measuring PD, it is possible to measure vertex distance, bifocal segment or progressive lens fitting cross height, frame wrap angle, and pantoscopic tilt. Being able to measure these parameters repeatably and accurately helps to assure that more personalized, digitally surfaced lenses will produce their intended visual results. Since there is considerable variation in how these systems operate, we will not attempt to give an explanation on individualized procedures for each one. (For more tablet-based systems, see Chapter 4, *Frame Selection* in the section called *Devices That Help in the Frame Selection Process*.)

NEAR PD

The near PD is required for single vision reading glasses or for multifocal lenses.

For *single-vision reading glasses,* the lenses are set so that their optical centers will be in the lines of sight of the eyes when the eyes are converged for reading.

For *multifocal lenses,* the distance portion is ground to correspond to the distance PD, whereas the bifocal or trifocal portion is decentered inward to be properly situated for near vision. The near PD can be either measured or calculated.

Measuring Near PD With a PD Ruler

To measure the near PD with the PD ruler, the dispenser is positioned at the subject's working distance; that is, at the distance for which the reading portion is prescribed.

Closing his or her poorer eye, the dispenser aligns his or her better eye directly before the subject's nose and instructs the subject to look into that open eye.

The PD ruler is lined up with the zero point corresponding to the center of the subject's right pupil. The ruler should also be held in the same plane in which the subject's new frames will rest as this will also affect the reading.

The dispenser then notes the measured point corresponding to the center of the subject's left pupil. This is the near PD (Figure 3.9). The subject is not required to shift gaze, and the dispenser is not required to change eyes during the procedure. (See Box 3.3 for a summary of this technique.)

It should be added that it is also possible to use the edge of the pupil or the limbus for reference points in taking the binocular near PD as long as only the right or only the left edges are used and not both outer or both inner edges.

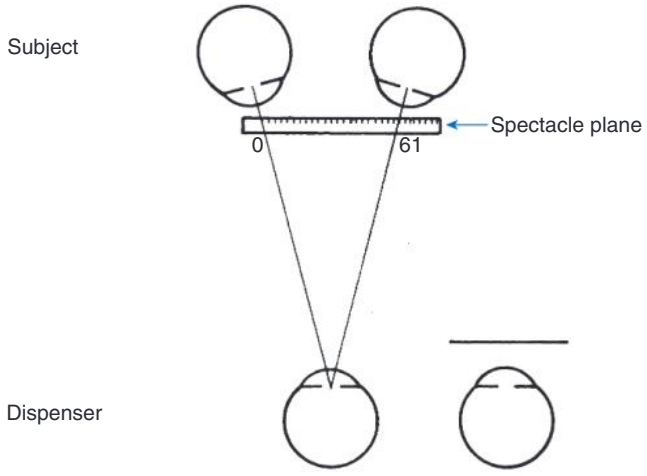

Figure 3.9 Using a interpupillary distance (PD) ruler, near PD may be taken with the dispenser positioned as shown. The distance between dispenser and subject is equal to the subject's working distance.

BOX 3.3 Steps in Measuring the Near PD

1. Dispenser places his or her dominant eye in front of subject's nose at the subject's near working distance. This is the distance for which the near prescription is intended—normally 40 cm (16 inches).
2. Dispenser closes the nondominant eye.
3. Subject fixates the dispenser's open eye.
4. Dispenser places the zero point of the interpupillary distance (PD) ruler at center of subject's right pupil.
5. Dispenser reads scale marking at the center of subject's left pupil.

In practice, many who use a PD ruler to measure the binocular distance PD will take the opportunity to measure the binocular near PD at the same time. Measuring the binocular near PD is done in the following manner. (Note that the first three steps are the same as the beginning steps for measuring binocular distance PD.)

1. Dispenser is positioned at 40 cm.
2. The dispenser closes his or her right eye and the subject, using both eyes, fixates on dispenser's left eye.
3. Dispenser lines up zero point of ruler on center of subject's right pupil. (This next step allows for the binocular near PD measurement.)

3A. The dispenser looks over at the subject's left eye and reads the scale on the ruler at the location of the left pupil center. This is a measure of the near PD for the distance from the subject to the dispenser.

The dispenser now continues the steps for finding the binocular distance PD as listed in Box 3.1.

Taking Near PD Using a Pupillometer

A PD-measuring instrument will allow both distance and near PD to be measured. This is done using a movable internal lens that changes the image distance and convergence for the subject. The near readings are carried out in the same manner as the distance readings.

USING THE NEAR PD FOR BIFOCAL SEGMENT INSET

For the near "reading" area of a pair of glasses to be used most comfortably, it must be positioned accurately in the lens. Horizontal placement of the near segment viewing area is determined by the near PD. (Vertical placement depends on frame depth and the individual's visual need and is covered extensively in Chapter 5.)

Because of the possibility of unequal monocular PDs, segment inset is usually specified individually for each eye. Ordinarily segment inset is the difference between the binocular distance PD and the binocular near PD, divided by 2:

$$\text{Segment inset} = \frac{(\text{distance PD}) - (\text{near PD})}{2}$$

For example, if the distance PD is 68 mm and the near PD is 64 mm, then the segment (seg) inset for each eye is 2 mm.

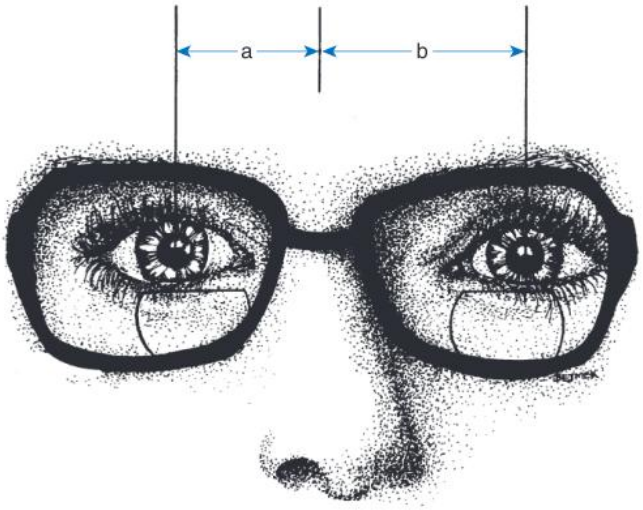

Figure 3.10 If there is a large difference in monocular interpupillary distances, insetting the bifocal segments from these points may result in a rather unusual looking pair of glasses. Using a wider segment size or changing to a progressive addition lens is a better choice.

Where inequality of the monocular PDs exists, this rule may result in errors, since both eyes may not be required to converge equal angular amounts for near fixation. The actual amount of error is usually so slight, however, that it is usually ignored. The exceptions would be cases of very marked differences in monocular PDs or very strong lenses.

If there is a large difference in monocular PDs, insetting the bifocal segments accordingly may result in a rather unusual looking pair of glasses (Figure 3.10). This effect can be made less noticeable by using a bifocal with a wider segment.

Calculating the Near PD

There are several other factors to be considered when calculating the near PD, most notably those that cause differences in segment inset.

Calculation

Finding the near PD by using similar triangles. The most logical way to calculate the near PD is to draw a triangle with the center of rotation of the eyes being two points of the triangle and the near point of fixation being the third. This is the main triangle (see Figure 3.11). A line is then drawn where the glasses will be worn. This creates a second, smaller triangle. We can then compare the second similar triangle to the original first triangle. The monocular near PD can be calculated from the monocular distance PD by using these two similar triangles.

Example 3.1

Let's start out with an example of a person who will be using his glasses at a normal 16-inch (40 -cm or 400- mm) reading distance. The glasses are to be worn at a 12.5 -mm vertex distance. (The vertex distance is the distance from the front of the eyes to the plane where the spectacles will be worn.) If he has identical right and left monocular distance PDs of 33 mm, what will his monocular near PDs be?

Solution

First, we need to find the distance from the centers of rotation of the eyes to the spectacle plane. The average distance from the front of the eye to the center of rotation of the eye is 13.5 mm. (This will vary some by individual, but for our purposes we can assume this distance to be accurate.) Therefore, the distance from the center of rotation of the eye to the spectacle plane will be 13.5 mm plus the vertex distance.

$$\text{Distance from the center of rotation to spectacle plane} = 13.5\,\text{mm} + 12.5\,\text{mm} = 26\,\text{mm}$$

To get the distance from the centers of rotation to the reading point, we add this to the distance from the glasses to the reading point. In this example:

$$13.5 + 12.5 + 400 = 426\,\text{mm}$$

To find the monocular near PD, we use similar triangles:

$$\frac{\text{Monocular near PD}}{\text{Distance from glasses to reading point}} = \frac{\text{Monocular distance PD}}{\text{Distance from eyes to reading point}}$$

$$\frac{\text{Monocular near PD}}{400\,\text{mm}} = \frac{33\,\text{mm}}{426\,\text{mm}}$$

$$\text{Monocular near PD} = \frac{(33\,\text{mm}) \times (400\,\text{mm})}{426\,\text{mm}} = \frac{13{,}200}{426} = 31\,\text{mm}$$

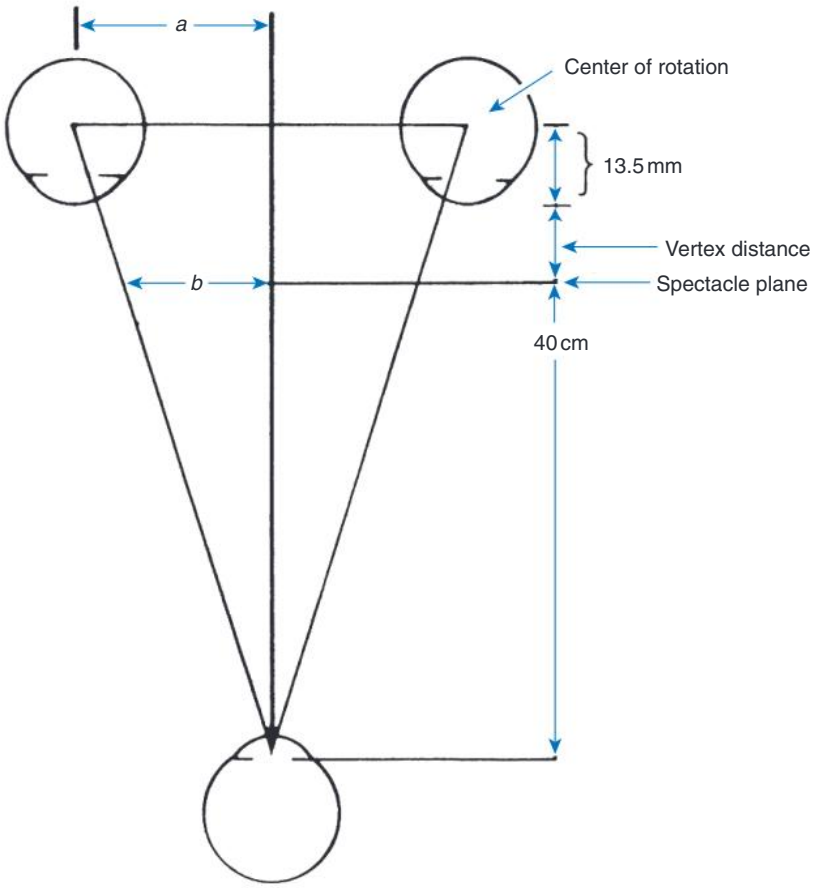

Figure 3.11 The distance from the front surface of the cornea to the center of rotation of the eye is normally considered to be 13.5 mm. (The diagram is, for clarity, not drawn to scale.) *a*, Monocularinterpupillary distance; *b*, calculated monocular near interpupillary distance.

Both right and left monocular PDs equal 31 mm. Knowing this, what would the amount of seg inset be? The seg inset for each eye would be:

$$\begin{aligned}\text{Seg inset} &= 33\,\text{mm} - 31\,\text{mm}\\ &= 2\,\text{mm}\end{aligned}$$

It is obviously easier to measure the near PDs with a PD ruler or pupillometer than to bother to calculate this way! Such calculations make more sense if the working distance is different from the usual, as in the case of shorter working distances. For example:

Example 3.2

An individual is to be wearing a pair of glasses for working at a distance closer than her normal 40- cm working distance. She normally wears a +2.50 add, but for this closer-than-customary working distance, her near prescription incorporates a near addition power of +5.00 D.

Her monocular distance PDs are 32 mm for both right and left eyes.

She is to be wearing glasses that are fit to a vertex distance of 13 mm.

By using similar triangles, find her calculated monocular near PDs and then the seg inset.

Solution

The first thing we need to find is the working distance. As previously stated, this person normally wears an eyeglass prescription with a +2.50 add at a 40-cm working distance. This means that she has no need to accommodate. However, since the add power is +5.00 D, the working distance from the spectacle plane will be less than 40 cm. Instead, it will be the reciprocal of the new +5.00 D add power.

$$\frac{1}{+5.00\,\text{D}} = 0.20\,\text{m (or 20 cm, or 200 mm)}$$

Now for the final calculations:

$$\frac{\text{Monocular near PD}}{\text{Distance from glasses to reading point}} = \frac{\text{Monocular distance PD}}{\text{Distance from eyes to reading point}}$$

$$\frac{\text{Monocular near PD}}{200\,\text{mm}} = \frac{32\,\text{mm}}{13.5 + 13 + 200}$$

$$\text{Monocular near PD} = \frac{(32\,\text{mm}) \times (200\,\text{mm})}{226.5\,\text{mm}}$$

$$= \frac{6400}{226.5} = 28.3\,\text{mm}$$

If we round to the nearest ½ mm, the monocular near PDs are 28.5 mm each. Therefore, the seg inset is:

$$\begin{aligned}\text{Seg inset} &= 32 - 28.5\\ &= 3.5\,\text{mm per eye}\end{aligned}$$

Finding segment inset by using the Three-Quarter Rule. Gerstman[3] simplified the calculation of the near inset with a rule that he called the *Three-Quarter Rule*. The Three-Quarter Rule states that for every diopter of *dioptric demand*, the optical center of each reading lens, or the geometric center of each bifocal addition, should be inset 0.75 (three-quarters) mm. Dioptric demand is the inverse of the reading distance from the spectacle plane in meters. *Dioptric demand is not necessarily the same as the bifocal near addition power (add power)!*

The Three-Quarter Rule gives a close estimate of seg inset per lens for individuals with binocular distance PDs between 62 and 68 mm. For those whose PDs are outside of this range, it becomes necessary to use similar triangles.

Example 3.3

An individual has a 64-mm binocular distance PD and is wearing a bifocal with an add power of +1.00 D. This person reads at the standard expected distance of 40 cm. Find the inset per lens and the binocular near PD using the Three-Quarter Rule.

(This example problem is not one for which the Three-Quarter Rule would normally be chosen. The reason for using this is because it shows two things. First, it will show how the results agree with other commonly used methods. Second, it shows the difference between add power and dioptric demand.)

Solution

Because this PD is between 62 and 68 mm, we can use the Three-Quarter Rule directly. To find the answer, we first need to know the dioptric demand. The dioptric demand is the inverse (reciprocal) of the working distance, *not* the inverse of the +1.00 add power. Therefore, since the working distance is 40 cm or 0.40 m, the dioptric demand is:

$$\frac{1}{0.40\,\text{m}} = 2.50\,\text{D}$$

Having found the dioptric demand, we can find the inset per lens by multiplying dioptric demand by three-quarters as the rule name implies. Therefore, the inset per lens is:

$$2.50 \times \frac{3}{4} = 1.9\,\text{mm of seg inset per lens}$$

The binocular near PD is found by subtracting both left and right seg insets from the binocular distance PD. Therefore the binocular near PD will be 64 − 1.9 − 1.9 = 60.2 mm.

The Influence of Distance Lens Power on Segment Inset

The power of the distance prescription influences bifocal inset. When a person looks at a near object, the eyes turn inward and are no longer looking through the optical centers of the lenses. Negative power, or minus lenses, keep the eyes from turning in (converging) as much as they normally would because of the Base In prismatic effect found at this point on the lens. Positive (plus) distance lens power causes the eyes to turn inward slightly more than they normally would because of the Base Out prismatic effect found at this point on the lens.

For plus lenses, both the measured or the Gerstman-calculated near PD would need to be reduced (i.e., the segment inset of the bifocal increases). For minus lenses, the near PD would need to be increased (i.e., the inset of the segment is reduced).

The position of the near reading area becomes more important when the reading area is small. This means that for progressive addition lenses, the position of the intermediate and near reading areas is very important. Progressive addition lens designers are now taking distance power into consideration when determining how much inset the near viewing area should have. Because the position of the progressive lens corridor is determined during lens design, only monocular distance PDs are used when ordering progressive addition lenses.

Segment inset formula. There is a formula that has been used for determining the amount of segment inset. This formula takes several factors into consideration. These factors are:

- The distance the lenses are from the eyes
- The distance PD
- The near working distance
- The power of the distance lens

Taking all these factors into consideration, Ellerbrock[4] derived the following formula for segment inset:

$$i = \frac{P}{1 + \omega\left(\frac{1}{s} - \frac{1}{f}\right)}$$

where

P is one half the distance of PD.

ω is the distance of the lens from the working near point.

s is the distance from the lens to the center of rotation of the eye. (The average distance from the cornea to the center of rotation of the eye is taken as being 13.5 mm. The vertex distance must be added to this 13.5 mm value to find s.)

f is the focal length of the distance lens in the 180-degree meridian.

All measurements are expressed in millimeters. This formula is helpful in that it shows that each factor may influence segment inset but is not one that would normally be used by an eyecare practitioner in clinical practice.

Examples for Finding the Near PD

Here are some examples for finding the near PD. Both the power of the prescription and the distance PD are known. Use the most appropriate method to find the segment inset and then the near PD.

Example 3.4

A spectacle lens wearer has the following prescription:

R : −1.00 D sphere
L : −1.00 D sphere
add : +2.00 D

The distance PD is measured as 64 mm. For a 40 -cm working distance, what are the expected methods for finding the near PD?

Solution

Since the working distance is 40 cm, simply measure the near PD with a pupillometer (or PD ruler). The distance power is low, so there is no real change in the seg inset because of the distance power factor.

Example 3.5

Suppose this same individual with a binocular distance PD of 64 mm and a distance prescription of −1.00 D sph for both eyes has a bifocal add of +3.50 D. The higher add is because of a shorter working distance. What would the binocular near PD be if the near working distance were 25 cm instead of 40 cm?

Solution

Since the working distance is less than 40 cm, we could find the near PD by a direct measurement using a pupillometer (or PD ruler) by similar triangles or by using the Three-Quarter Rule. To find the near PD by measurement, the first choice would be to use a pupillometer or a computer tablet equipped to measure PDs. Unfortunately, most do not measure for distances this close. However, it is possible to use a PD ruler. If a ruler is used, the dispenser's eye position must be at the subject's near working distance.

If the near PD is to be calculated, use the Three-Quarter Rule. To use the Three-Quarter Rule, begin by finding the dioptric demand. Dioptric demand is the reciprocal of the working distance in meters. In this example, the working distance is 25 cm, or 0.25 m. Therefore,

$$\text{Dioptric demand} = \frac{1}{0.25\,\text{m}} = 4.00\,\text{D}$$

Next, to find the inset per eye, the dioptric demand is multiplied by 3/4.

$$4.00 \times \frac{3}{4} = 3\,\text{mm per eye}$$

Thus, the near PD will be:

$$\text{Distance PD} - (\text{segment inset OD}) - (\text{segment inset OS})$$
$$\text{or}$$
$$64 - 3 - 3 = 58\,\text{mm}$$

This means that a prescription for a person with a bifocal add and a 25 -cm working distance should have the distance optical centers set for a far PD of 64 mm and the segments set for a near PD of 58 mm.

It bears repeating that the dioptric demand is the inverse (reciprocal) of the wearer's working distance in meters. If the wearer is an absolute presbyope with no accommodation, then the inverse of the working distance (the dioptric demand) will equal the power of the near addition. But if the wearer is not an absolute presbyope and still has some accommodation remaining, the dioptric demand and add power will not be the same. The example just given demonstrates this.

Example 3.6

A prescription reads as follows:

R : −8.50 D sphere
L : −8.50 D sphere
add = + 1.50

For this prescription, the distance monocular PDs have been measured. They are both 31 mm. For a 40 -cm working distance, how would you find the near monocular PDs?

Solution

This prescription is for the normal working distance. If we use the pupilometer, the expected result for the monocular near PDs would be 29 mm each. (This is nearly the same as would be found using similar triangles.) The inset is 2 mm for each near segment.

However, this prescription is fairly high minus. If we were to also take distance power into consideration by using Ellerbrock's formula, the inset would be ≈1.6 mm each. To the nearest 1/2 mm, the monocular near PDs would be ≈29.5 mm each.

R : 28 mm − 1.5 mm or 26.5 mm
L : 31 mm − 1.5 mm or 29.5 mm

For high-powered lenses that are to be worn at shorter working distances, the more accurate method would be to use Ellerbrock's formula. With high-powered lenses, calculated near PDs will be more accurate than measured near PDs because measured near PDs do not take the prismatic effects of high plus or high minus spectacle lenses into consideration.

Obviously, we aren't going to do all of these calculations to find near PDs! So what would we do?

From a practical standpoint, measure the near PDs with a pupillometer. If the prescription is high minus, slightly decrease the amount of inset found. (Decreasing the inset is the same as increasing the near PD.) As the eyes look inward, this compensation allows for the effect of Base In prism caused by the minus distance lenses.

If the distance power is high plus, do just the opposite. Slightly increase the segment inset. (Increasing segment inset is the same as decreasing the near PD.) As the eyes look inward, this compensation allows for the effect of Base Out prism caused by the plus distance lenses.

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3. Gerstman DR. Ophthalmic lens decentration as a function of reading distance. *Br J Physiol Opt.* 1973;28(1):34–37.
4. Ellerbrock LR. A clinical evaluation of compensation for vertical imbalances. *Am J Optom Arch Am Acad Optom.* 1948;25(7):309–325.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. True or false? When taking PD measurements, the person measuring covers or closes one of his eyes at a time. He *never* covers one of his subject's eyes.
   a. True
   b. False
2. When is it especially important to use monocular PD measurements?
   a. When eyes are asymmetrically placed.
   b. When the prescription lenses are of high power.
   c. When the lenses are aspheric.
   d. When the two lenses are considerably different in power from one another.
   e. When progressive addition lenses are used.
   f. It is important to use monocular PD measurements in all the above circumstances.

3. May the limbal edge be used as a reference point in taking monocular PDs?
   a. Yes
   b. No
4. True or false? Using a corneal reflex instead of the center of the pupil is currently an accepted method of finding PDs with a pupillometer.
   a. True
   b. False
5. For measuring monocular PDs using the lenses in the sample frame and a marking pen, which of the following is the correct procedure?
   a. The dispenser should mark the lenses on the horizontal midline, directly below the pupil center.
   b. The wearer should look at the bridge of the dispenser's nose. The dispenser should view the wearer's right eye with his or her left eye and the wearer's left eye with his or her right eye.
   c. The dispenser should mark the lenses at the center of the wearer's pupils. The wearer can view either the bridge of the dispenser's nose or a distant object if the gaze is held fixed.
   d. The dispenser should mark the lenses at the center of the wearer's pupils. The distance between the marked dots is measured. This distance divided by 2 will yield the right and left monocular PDs.
   e. There is a flaw in every one of the above answers. None of them are true.
6. If there are large differences in the measured monocular PDs for bifocal lenses, how may an unusual cosmetic result be avoided?
   a. Use larger flat top segments instead of smaller ones.
   b. Switch to progressive addition lenses.
   c. Switch to invisible bifocals.
   d. All the above may solve the cosmetic problem.
7. If the distance PD measures as 64 mm and the near PD calculates out as 59 mm, what is the seg inset per lens?
   a. 1.5 mm
   b. 2.0 mm
   c. 2.5 mm
   d. 5.0 mm
8. A person has a prescription that calls for a +4.00 add power. Given no further instructions, for what distance would you measure the near PD?
   a. 40 cm
   b. 30 cm
   c. 25 cm
   d. 20 cm
   e. arm's length
9. For bifocal lenses with a high plus correction, the near PD should be:
   a. increased slightly over the measured value.
   b. decreased slightly from the measured value.
   c. left the same as the measured value.
10. Here is a prescription for a presbyope with no ability to accommodate. (Such a person is called an *absolute presbyope*.) This person has a binocular distance PD of 64 mm. The prescription reads:
    OD: +1.00 sph
    OS: +1.00 sph
    +5.00 add
    According to the Three-Quarter Rule, to the nearest 0.5 mm, what is the near segment inset per lens?
    a. 1.5 mm
    b. 2.0 mm
    c. 3.0 mm
    d. 4.0 mm
    e. 5.0 mm
11. Near PD can either be measured or calculated. When measured, the distance from the dispenser's eye to the subject's spectacle plane should be:
    a. the proposed working distance.
    b. the near point of accommodation.
    c. 40 cm.
    d. 33 cm.
    e. arm's length.
12. A person has a distance PD of 66 mm, a low distance prescription, and a bifocal add that requires the reading material be held at 25 cm. Rounded to the nearest 0.5 mm, what should the seg inset be for each lens?
    a. l.5 mm per lens
    b. 2.0 mm per lens
    c. 3.0 mm per lens
    d. 4.0 mm per lens
13. Suppose an individual has a distance PD of 64 mm, a distance prescription of −1.50 D sph for both eyes, and a bifocal add of +3.00. To the nearest 0.5 mm, what would the near PD be if the near working distance were 20 cm instead of 33 cm as would be expected if the wearer had no accommodation?
    a. 55 mm
    b. 57.5 mm
    c. 56.5 mm
    d. 60 mm
    e. 61 mm
14. The distance prescription has no power; that is, 0.00 D. However, the near add is +5.00 D. The distance PD is measured as 68 mm. If the prescription is to be made as single vision lenses and the wearer has no accommodation, which statement is true?
    a. The near PD needs to be compensated for the +5.00 D add power as if it were the distance power, since the whole lens has a power of +5.00 D.
    b. PD is unimportant since there is no power in the distance prescription.
    c. Reduce the measured distance PD by 4 mm to find the near PD.
    d. All the normal rules apply for finding the near PD. The optical centers of the +5.00 D single vision lenses are horizontally positioned just as if they were the centers of the segments of a bifocal lens, but the near PD must be measured at a 20 cm distance from the spectacle plane.
15. A prescription reads as follows:
    R: −9.00 D sph
    L: −9.00 D sph
    add = +2.50
    For this prescription, we will assume that the distance and near monocular PDs have been measured. The right monocular PD was measured as 32 mm and the left as 34 mm. The right monocular near PD was measured as 30 mm and the left as 32 mm. Given the power of the distance lenses, for a 40 -cm working distance, what monocular near PDs might you order?
    a. Both right and left would be ordered as 31.5 mm
    b. Right 30 mm and left 32 mm
    c. Right 31 mm and left 33 mm
    d. Right 30.5 mm and left 32.5 mm

4

Frame Selection

USING THE WEARER'S OLD FRAME

Sometimes a person wants to use their old frames instead of selecting something new. This may or may not be appropriate.

There are a number of valid reasons for wanting to use the old frame and not purchase a new one. These include cost, comfort of the old frames, and sometimes the inability of the wearer to look in the mirror with any other frame and still have what they see look right to them. Even though any of these could be considered valid, there are other factors that usually outweigh keeping the old frame. However, even if there are valid reasons not to use the old frames, if the wearer has been fully informed of the pitfalls and still persists, their desires should be respected.

Factors to Consider Before Using the Wearer's Old Frames[1]

There are certain precautions that must be considered before using the old frame for the new prescription. These are the most common:

- Putting new lenses in an old frame may involve putting additional stress on the frame. Older frames may not withstand that stress very well, particularly older plastic frames that have become brittle with age. Sometimes frames will withstand the stresses of the new lenses but be weakened, only to break before a new prescription is required.
- It is hard to predict how long an old frame will last. Will it last the life of the new lens prescription? If the frame breaks, it is not a simple task to find another frame into which those new lenses will fit.
- If the old frame needs repairing in the future, will there be parts available? A used frame may already be discontinued. If it has been and there are no parts available, any savings could be lost when both frames and lenses need to be repurchased.
- Usually, people keep their old glasses as a backup spare pair in case they lose or break their new pair. Using the old frames eliminates the emergency backup.
- If the existing frames have not been discontinued and the wearer decides to get exactly the same frame, there is an advantage to having interchangeability of parts should the new frame break.
- Does the lab need the old frames to make the new lenses correctly? If so, can the wearer do without their current glasses while the frames are at the laboratory?
- Are the old frames out of style or nearly out of style? If they are nearly out of style, what will these older frames look like by the time the wearer is ready for the next prescription change?
- In summary, there are a number of reasons why people may not be well-served in keeping their old frames. These reasons have to be logically and carefully explained; otherwise the wearer will conclude that the dispenser is only interested in their own financial gain.

COSMETIC CONSIDERATIONS

From an aesthetic point of view, glasses are of no small importance to the person wearing them. Each individual expects and should receive help not only with sizing, but also with the cosmetic aspects of a frame.

The habitual wearer often needs just as much help in frame selection as the new wearer because individuals are accustomed to seeing themselves in the frame style they are presently wearing. Any new frame will represent a change and will look strange. The wearer who is forced to change frames because the style has been discontinued will be especially dependent on the advice of the person fitting the frames.

Despite continuous changes in frame styles, there are still certain basics that can be used to arrive at an aesthetically pleasing and comfortable frame. The wearer ultimately has the final choice of what will be worn but should not be allowed free rein in selecting a frame.

Frame selection is often a process of trial and error, can be time-consuming, and is frequently frustrating. An experienced fitter aware of the basics of frame selection can save considerable time and earn the wearer's gratitude by being able to readily select several frames that are obviously suitable.

Proper assistance in frame selection is especially important for the type of person who may be inclined to accept the first frame presented. Unless such a frame consists of a good bridge fit, proper eye size, and an acceptable shape, the fitter may inherit the almost impossible task of attempting to adapt a frame to a face for which it was not designed.

At the same time, what is cosmetically correct for a given face must be related to whatever styles are in vogue. At a time when narrow frames are in fashion, a person whose face requires a deep frame will not wear one quite as deep as when larger, deeper frames are in style. Just as changes in styles of clothing—longer or shorter hemlines, wider or narrower neckties—become customary by repetitious display, so do variations in spectacle designs. Thus, when basics in frame selection are noted, it is understood that they are applied within the framework of current eyewear trends.

Frame Size Overview

Perhaps one of the first considerations is to pick a frame size that is a reasonable match for the wearer's PD. Look at the sum of the frame's eye and bridge sizes. Compare this sum to the wearer's interpupillary distance (PD). How much larger is the sum of the A + DBL (distance between lenses) compared to the wearer's PD? If the difference is considerable, the glasses are going to overwhelm the face.

The next logical question is going to be, "Tell me how many millimeters larger is too many? 6 mm? 10 mm?" Unfortunately there is not a specific cut-off point. The answer depends upon more than just a numerical value. It will depend upon current style. Styles change in cycles from smaller eye sizes to larger eye sizes and back again. So this number will be comparative, depending upon what everyone else is wearing at the time. It will also depend upon the effective diameter

(ED) of the frame shape. A larger ED will make a frame with a large eye size (A dimension) appear to be even larger.

Remember, we are speaking of the wearer's PD here—not the size of the head. A person with a large head and a small PD should not be wearing the same sized frame as a person with an equally large head and a large PD.

Frame Shape and Face Shape

Since frames are exceedingly obvious on the face, their shape tends to emphasize or deemphasize characteristics of the face. A good frame selection can be simplified by considering first which facial lines are complimentary to the person. Those lines should be emphasized through repetition, usually by the upper and lower eyewires. On the other hand, uncomplimentary lines should not be repeated by the frame line.

Because a hairstyle can also alter the apparent shape of the face, frames are generally chosen to compliment the face as it appears with the hairstyle being worn at the time of frame selection. A radical change in hairstyle may also radically change the effect that the frame has on the face.

Few faces meet the artistic ideal in bone structure and conformity. A well-selected frame can increase the attractiveness of a face by emphasizing those planes and lines that are complimentary. Conversely, a frame that tends to overemphasize or repeat the less complementary aspects of a face may have an unintended negative result.

In most instances, the lines of the frame selected should create the effect of balancing facial lines and shapes.

TABLE 4.1 Fitting by Face Shape

Basic Facial Shapes	Fitting Shapes		Fitting Suggestions
Oval	Average		May wear most any type
Oblong	Long face	Contrasting shapes	Deep frame Low temple attachment
Round Square	Wide Face	Contrasting shapes	Narrow frame High temple attachment
Base-down triangular	Erect (base-down) triangular face	Contrasting shapes	Fit size to largest part of lower facial area Dark colors or bolder look are in order
Inverted triangle Diamond	Inverted (base-up) Triangular face	Contrasting shapes	Unobtrusive frame (metal or rimless works well) Light or medium weight frame Lighter color is in order Rounded lens shape Delicate characteristics of frame for women

Facial Types

Knowledge of basic facial shapes is not essential for appropriate frame selection, but it is a valuable aid in making a quicker and more accurate decision about a specific frame. The average fitter can tell how appropriate a frame looks after it has been placed on the face. The accomplished fitter who understands facial shapes will know how a frame will look before placing it on the face.

The awareness of the considerable influence that spectacle frames can have on the basic facial shape, either positively or negatively, is essential to competent selection of the ultimate frame for each specific face.

Generally, there are seven basic facial shapes:

1. *Oval*—considered to be the most versatile type regarding which frames may be worn
2. *Oblong*—thinner and longer, with the sides of the head being more parallel to one another than in the oval face
3. *Round*—more circular than the oval face
4. *Square*—again, the sides of the face are more parallel than in the oval face, with the face being wider and shorter than average
5. *Triangular*—the lower part of the face is wider than the upper part
6. *Inverted triangular*—the upper part of the face, the temple area, is wider than the lower jaw area
7. *Diamond*—the central section of the face is wider, with the upper and lower extremities of the face narrowing down considerably (Table 4.1)

To simplify the face shapes to help choose frame width and depth, the seven shapes can be condensed to the following five shapes.[2] The oval face is considered *average* and can wear almost any frame, so only the general rules apply. The oblong face is simply referred to as *long*. Both the round and the square face fall into the category of the *wide* face. The *erect*, or base-down, triangular face is a category that does not lend itself to condensation. For fitting purposes, the diamond face is included in the *inverted*, or base-up, triangular classification, since these two shapes are both fit in basically the same manner. Using this simplified system, a face may deviate from the average in four essential ways: it may be either longer, wider, or more triangular, with the base of the triangle up or down.

Affecting the Length of the Face

For purposes of frame selection, we are concerned with the vertical and horizontal *dimensions* of the frame, the roundness or squareness of the frame *shape*, and the *coloration* of the frame front.

For simplification, discussion of frame shape suitability can be broken down into two categories.

- The first concerns the width and depth of the frame (the frame dimensions). This would include whether the emphasis should be in the upper portion of the frame, as with a nylon cord frame with a dark, heavy upper portion. In contrast, the emphasis may be even across the entire frame, as with a frame that is a solid color with upper and lower rims close to the same thickness. These considerations relate to the length and breadth of the face.
- The second category deals with the angularity or roundness of the frame line (shape) as related to the angularity or roundness of the face and the eyebrow line.

The proper *width* of the frame can be gauged as approximately equal to the widest part of the skull's facial bone structure. (In this case, the term *width* is taken to mean the outer width of the frame itself and not simply the location of the outer edges of the lenses.) This "rule" is subject to modification with style changes. However, the widest bony part of the face is always used as the reference point. The bone structure is used instead of actual facial width because excess body and face weight may cause the wearer's features to appear to be set in towards the center of the face. A frame based on the width of the actual face rather than structure could cause the person to appear cross-eyed.

As a rule, the longer the face, the greater the vertical *depth* (distance from the upper to the lower rim) should be to keep the frame

proportional to the face. The shorter the face, the smaller the vertical depth. In other words, a deeper frame is more complimentary to a long face, whereas a narrower frame lends itself more easily to a wide face. In a sense, the frame "covers" part of the face and covering more of a long face gives the illusion of reducing its length.

Frame fronts may have a more noticeable upper portion, or they may be more even in rim thickness and color. A darker, solid-colored frame will aid the effect of shortening a long face more readily than a frame that draws the viewer's attention to the upper part of the frame. For example, a nylon cord frame with a dark upper portion would fall into this category. A solid frame seems to shorten the length of the face in the area extending from the dark lower rim to the chin.

On a frame with a dark upper rim section and a lower rimless or nylon cord section, the reference point for face length is from the dark part of the frame at eyebrow level (the part that immediately catches our eye) to the bottom of the chin. Thus, these frames have a face-lengthening effect, making them more compatible to the wide face.

Spectacle *temples* interject an artificial dividing line. The lower the line, the shorter the face appears; the higher the line, the longer it appears. Thus, for long faces, frame fronts with lower endpieces shorten the face. For wide faces, temples with high endpieces add length to the face.

When the face is viewed from the side, it is divided by the location of the spectacle temple, which interposes an artificial dividing line.

If the temple attaches high on the frame front, there is more facial area below this line, and the face appears lengthened (Figure 4.1, *A*). If the temple is attached lower on the frame, there is less distance from this line to the bottom of the chin, and the face appears shorter (see Figure 4.1, *B*). If the face is long, lower endpieces will help give the appearance of less length; if the face is wide and short, higher endpieces are desirable.

An extreme case of the wide face would be one with smallish features that appear to be bunched centrally in the middle of a large face.[2] As a person gains weight, head size increases but features remain stationary. This may give facial features a "bunched-up" look. Therefore, the width of the frame should be gauged by the bone structure of the face and not by the actual widest part of the head. Otherwise, the person's face will be overpowered by the frame or the eyes will appear abnormally close together.

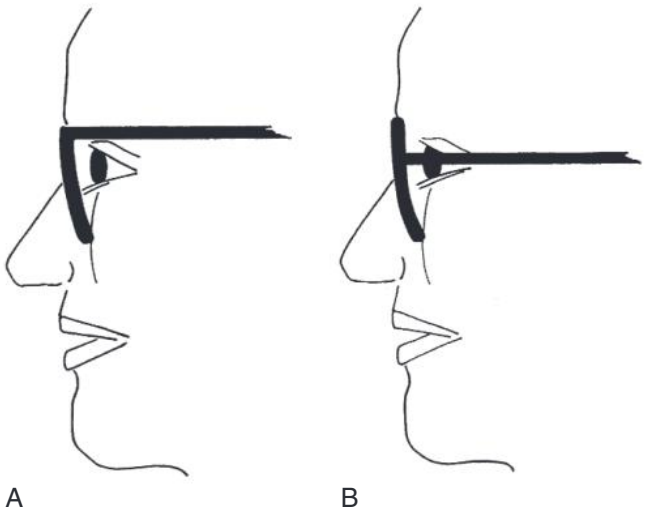

Figure 4.1 **A,** If the temple attaches high on the frame front, there is more facial area below this line, and the face appears lengthened. **B,** If the temple attaches lower, there is less distance from this line, and the face appears shorter.

The same rules that apply to fitting the wide face also apply to the pudgy face but must be adhered to more strictly. The less obvious the frame, the better. In a plastic frame, a medium to lightweight plastic would be appropriate, but a better alternative is the thin metal, nylon cord, or even rimless frame. Attention also must be given to the vertical dimension of the frame.

Affecting Facial Balance

With faces somewhat wider in one area than in another, frames can be used to balance out a wider area and shift the facial emphasis.

The widest part of the *base-down triangular face* is the lower area. Simply wearing glasses often enhances the appearance of the face because the frames lend balance. To provide balance, the frames themselves should be approximately the same width as the lower facial area. The actual width will vary somewhat, depending on current frame styles.

An oval or upswept shape is preferable as opposed to one of rectangular design. This is particularly true of the lower rim, which, if it is a straight line paralleling the jawline, tends to emphasize the width of the base of the triangle. Frames for men in these cases may appear satisfactory with somewhat squared-off shapes because the lower line is not continuous and angular lines in a man's face are not considered uncomplimentary. For women, a frame with rounded lines will give a softer, more feminine look and squared-off lines a more assertive look.

The frame should be a dark color for emphasis to further balance the overall facial shape: solid if the face is long or with emphasis on the upper part of the frame if the face is short.

The *base-up triangular face* is somewhat more difficult to fit. It is not possible to use the mere location of the frames to counterbalance the wider part of the face. Obviously a prominent frame on this type of face draws attention to the wider facial area.

To avoid undue emphasis, the frame should be as unobtrusive as possible. The frame should have the minimal width that still stays within current fashion lines. Keep in mind that the farther out the frames extend from the side of the head, the more pointed the chin will look.

The frame should be of light or medium weight and of a lighter color when possible. Metal or rimless-like varieties lend themselves well to this type of face.

A heavy lower line sometimes helps to counterbalance. A rounded lens shape will soften the triangularity of the face, but a squared-off frame will emphasize it. This type of face on a woman usually has a certain delicateness to it; thus, the frame should also have delicate characteristics.

Frame Lines

Repeating a facial line through the line of the frame emphasizes the facial line. This can be used to advantage provided the line being repeated is complementary or used to achieve a desired effect. Inadvertently repeating an uncomplementary line can, by the same principle, have an undesirable effect.

The lines of the frame are determined by the curve or squareness of the upper and lower rims—in other words, by the basic shape of the lens. At this point, the depth and width of the desired frame should be fairly well known, depending on the length, width, or triangularity of the face.

With conventional frame selection, when using the frame shape for cosmetic emphasis, the upper areas of the frame are determined by the eyebrow line, whereas the lower frame areas are determined by the lines of the cheek and jaw. The lower eyewire area near the nose should follow the nasal contour of the face, as discussed previously.

The *upper frame area*, or upper rim, should have the same basic shape as the eyebrow itself. Too much deviation from this line may create a disharmonious look to the face, roughly similar to the confused effect of wearing stripes with plaids. Ideally the upper rim should follow the lower edge of the eyebrow, leaving it visible. At its highest position, the upper rim bisects the eyebrow. However, considering the influence of style and strength of wearer preference, this is not always possible or desirable. Some even prefer an above-the-eyebrow position. In any case, the most important thing to be kept in mind when dispensing conventional eyewear is to follow the basic line of the eyebrow with the upper line of the frame.

As far as the *lower frame area* is concerned, apart from a squared or rounded effect, which is determined by the squared or rounded aspects of the face, the most important thing a lower rim can do is add a lift to a face that has begun to sag with age. Using an upsweep on either upper or lower rim of a frame tends to counteract the downward lines of the face. In general, a frame with a downward line, which emphasizes the undesirable characteristic, should be avoided for such individuals.

Frame lines can somewhat alter the mood expression of the face, causing the wearer to have a happier, sadder, sterner, or even a somewhat surprised look, depending on the interaction of the frame lines with the background facial configuration.

Another important effect that may be accomplished through the use of lower rims is to help conceal the bags that many people have under their eyes. Helpful camouflage is attained by choosing a frame with fairly thick lower rims of a dark color, properly positioned to cover the lowest part of the bags.

Frame Color

Up to this point, frame color has been noted essentially regarding how certain effects can be emphasized through the use of a darker color or deemphasized through the use of a lighter color. Although the actual color chosen may be left to the wearers, the dispenser has a responsibility to guide them towards the final choice.

Hair color, skin color, feature size, and eye color can all give valuable clues to the suitability of eyewear color. With all the possible shades and degrees of translucence in available frames, plus innovative uses of color combinations, firm rules to guide color selection are difficult.

Clothing and accessories. The common-sense rules that apply to clothing and accessories also apply to the proper choice of eyewear. Certainly, the favorite or dominant color that the individual regularly wears ought not be overlooked. Choosing a frame color should not be done based on skin, eye, and hair color at the exclusion of habitual dress. Eyeglasses are accessories and it has been traditionally said that "the best dressed are identified by accessories repeating tones in the ensemble."[3]

Considering that most people do not wear the same colors continually, it should be understood that one single frame cannot be expected to coordinate with every possible mode of dress—both in color and in effect. Those who choose one pair of glasses to serve in every work or recreational situation, with every style and color of clothing, should be aware of the limitations this imposes. Keep in mind that such a situation does present an opportunity to introduce the need for more than one pair of glasses. This is true not only from a cosmetic standpoint, but also from an occupational or safety perspective.

Hair. People with thicker, darker hair are more often able to complement their appearance in heavier, darker, bolder frames than individuals with lighter, finer hair might. A lighter-colored, more delicately styled frame is recommended for the person with light, fine hair. A bold dark frame on a person with light, fine hair draws attention to itself much more emphatically than it would on someone with thicker, darker hair.

When a metal frame is to be dispensed, those with blond, light brown, or red hair can wear gold well; those with gray hair can wear silver well. Those with black or extremely dark hair can wear either color well. Individuals with salt-and-pepper hair or hair that is just starting to gray will find that choosing a silver frame may make the "salt" component of their salt-and-pepper hair more noticeable.[3] It should be kept in mind that not everyone may consider choosing a frame color that will emphasize beginning grayness to be a detrimental choice. Much depends upon the image the individual wishes to project. Therefore, the role of the dispenser becomes that of an aide in helping a person find a frame that produces the desired effect, while avoiding any unintentional changes the wearer may consider unpleasant.

Facial features. As far as facial feature size is concerned, the smaller and more delicate the features, the lighter the frame color can be; the heavier the features, the darker the frame color allowable.

Narrow and wide-set eyes. A person whose eyes are set close together in comparison to the total width of the face will want to choose eyewear that does not draw attention to the center of the frame. Low-set, thick, dark-bridged frames will make such an individual look as though the eyes are so close together there is hardly room for the frame to sit on the nose. Instead, this person should choose a frame with little central emphasis but with distinctive upper temporal areas. In this way, the observer's attention is drawn outward and away from the close-set eyes.[4]

An individual with extremely wide-set eyes needs the exact opposite. The best choice is the frame with a low-set, dark, thick bridge. The space between the eyes is "filled in," and the eyes do not appear as widely spaced.

Lens Tint

There are many purposes for a tint in prescription eyewear—so many, in fact, that a complete chapter in this book is devoted to the subject. Yet, sometimes the only reason a person wants tinted lenses is cosmetic. When this is the case, the color of the tint is usually coordinated with the frame.

Frame Thickness

Many of the effects caused by the lightness or darkness of a frame go hand in hand with frame color. As with frame color, the smaller and more delicate the features, the lighter (thinner) the frame should be. The larger and broader the features, the heavier (thicker) the frame should be.

One exception is a man with large, broad facial features who is smaller in stature than would be expected for the ruggedness of the face. To help neutralize the effect of a head that may otherwise look out of proportion to the body, a frame weight lighter than normal might be used.[5] The size must not be too small for the face, however, because a frame that is too small for the face is still too small, whatever the size of the body. A bold frame look can be created by using a dark color despite the reduction in frame thickness (Table 4.2).

TABLE 4.2 Fitting by Frame Weight

Frame Weight	Indicated for
Heavy	Large, broad features
Medium	Normal features, large features, and small stature
Light	Small, delicate features, women with childlike features, children

Children and women with childlike features are especially complimented by a thin frame. Using a frame too thick for these features will easily overpower the face and create a puny appearance rather than add a complimentary facet to the face.[5]

Occasionally, the fitter will encounter a person whose features are not strong enough for a heavy frame but who wants the heavy frame look. The answer is to use a frame of medium thickness in a very dark color. The dark color makes the frame appear heavier. Similarly, a frame with less visible lower rims makes the weight appear less than it really is.

When in doubt as to which frame weight to choose, always select the lighter weight.

Bridge Design

Frame selection can cause the nose to appear longer or shorter than it really is, depending on the frame bridge chosen. Apparent nose length depends on the extent of nose visible beneath the frame bridge, just as apparent face length depends on the area of face observed below the frame.

To "lengthen" the nose, choose a frame that exposes as much of the nose as possible (Figure 4.2). An open-bridged frame allows most of the nose to be seen because it rests on the sides and not on the crest of the bridge.

Dark frame colors draw attention to the surrounding facial area and tend to emphasize whatever characteristics are created by the fit of the frame. In the case of the keyhole bridge, using a dark frame color will increase the illusion of nose length. If for reasons of physical fit, the keyhole bridge must be used on a person with a long nose, the lengthening effect will not be as emphasized if the bridge is clear or light-colored or if a frame with darker endpieces is used.

The saddle bridge is designed to cut across the crest of the nose. The lower the bridge, the greater the effect of shortening the nose (Figure 4.3). A darker color will give a sharper demarcation and make the nose look shorter still, whereas a lighter color tends to reverse the effect.

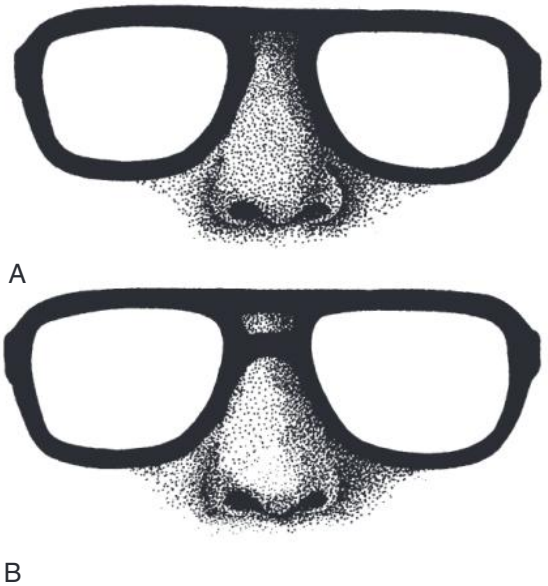

Figure 4.2 To "lengthen" the nose, a frame is chosen that exposes as much of the nose as possible. The frame in **(A)** achieves this; the frame in **(B)** does not.

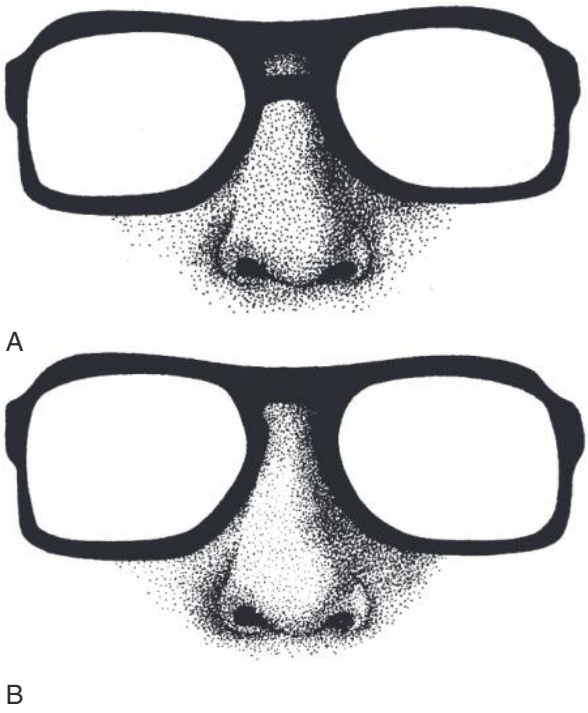

Figure 4.3 The lower the bridge, the greater the impression is of shortening the nose. The bridge in **(A)** achieves this; the bridge in **(B)** does not.

FITTING CONSIDERATIONS

Many difficulties associated with adjusting a pair of spectacles appropriately rest with errors in the initial fitting or selection of the frame. Once the lens size and shape have been selected, the essence of the well-fitted frame rests in the choice of the proper bridge and the proper temple style and length. The spread of weight or force over the largest surface is the objective for both pads of the bridge and the behind-the-ear portion of the temple.

The Bridge

When the bridge is fixed, as in most plastic frames, the choice of the appropriate bridge is determined by how well the weight of the frame is borne on the nose. If the bridge is not properly selected, attempts to adjust the frame and the bridge to secure wearer comfort are exceedingly difficult and essentially hopeless.

The appropriate bridge is determined by its width, the position of its pads, the frontal angle of the bridge at the pads, the flare or splay angle of the pads, and the vertical angle of the pads. The bridge selected should not allow the lower rims of the frame to ride on the cheeks.

That being said, even when the bridge size is correct, when frame styles are large and deep, some wearers with smaller or shorter faces may still insist on a frame with a larger vertical size. This is likely to cause the lower rim to rest on the cheeks. When this happens, these individuals should be told that when they smile, the frames may move upward. In addition, the lower portion of the lenses can fog up, need more frequent cleaning, and become irritating to the cheeks.

If the bridge is too narrow, the upper rim may be above the eyebrows.

To check bridge size, lift the frame very slightly from the nose and move it to the left or right. There should be about 1 mm of clearance between the nose and the free side of the bridge.

A plastic frame will almost always have a fixed bridge. In other words, it does not have the adjustable nose pads usually found on metal

and rimless frames. When selecting a plastic frame, know that the bridge of the frame must contour the shape of the bridge of the nose. Ask yourself this question. "With this frame, do I have an ability to adjust it to fit better later?" If the answer is no, select a different frame.

(There are specific names for the dimensional angles of the nose. These angles correspond to frame bridge and nose pad angles. An understanding of these angles is helpful in mastering frame selection. They will be covered more extensively in Chapter 8, *Standard Alignment*, and Chapter 9, *Adjusting the Frame*.)

Temples

The distribution of forces necessary to hold a frame in place on the face generally shifts from the nose to the ears as the head is bent forward. Thus, the activity of the wearer and the intended use of the spectacles should be considered to determine the temple style that is appropriate (Table 4.3).

Spectacles with flat, straight-back, or library temples are suitable when they are taken off and on often. This happens when the spectacles are to be worn only occasionally or primarily for reading or desk work.

The commonly occurring skull and convertible temple styles are appropriate if the wearer's activity requires a normal amount of movement or constant wear.

If the head is to be lowered markedly, the individual is physically active, or the person has a job requiring unusual head positions, then riding bow or comfort cable temples are preferable.

All temples help hold the lenses in place primarily by the area of contact with the side of the head—not by pressure just at the tip of the temple or by bending the temple so far down that it presses against the back of the ear. Proper length is therefore important in frame selection. The temple should be long enough so that the bend of the temple may be positioned just barely past the top of the ear (see Figure 9.12). The exact fit of the bent-down portion against the head can be achieved during adjustment of the frame.

Selecting Frames for the Progressive Addition Lens Wearer

A progressive addition lens wearer needs a frame with:

1. A minimal vertex distance.
2. An adequate pantoscopic tilt.
3. Sufficient vertical depth in the nasal portion of the frame shape.

A *minimal vertex distance* (with the frame front close to the eyes) is required because of the relatively narrow viewing areas afforded by the progressive optics of the lens for intermediate and near distances (see Chapter 20). The closer the progressive viewing zone is brought to the eye, the wider the intermediate and near viewing areas will be.

TABLE 4.3 Fitting Temple Styles

Temple Style	Indicated for	Contraindicated for
Comfort cable or riding bow	Active people Jobs requiring unusual head positions Young children Especially heavy frames	Off and on wear
Straight back	Off and on wear	Heavy lenses Persons with parallel-sided noses Persons with flat noses Frames with weak fronts
Skull	Normal, everyday wear	Jobs requiring unusual head positions

Using a frame with an *adequate pantoscopic tilt* (with the lower rims of the frame closer to the face than the top rims) will help to bring the lower (reading) half of the lens even closer to the eyes. Then when the eyes are turned downward for near viewing, the reading width will be further increased.

The shape of the frame is important with progressive addition lenses.

- If the lens has too much of the lower nasal area cut away, as with the classic aviator shape, the reading area is reduced (Figure 4.4, *A*).
- When the lens is narrow vertically, much of the near viewing area will be lost (see Figure 4.4, *B*). This loss may be prevented if a progressive lens specifically designed for frames with narrow vertical dimensions is chosen. However, even if such a lens design is used, frames with an extremely narrow vertical dimension will still not work well for progressive addition lenses.

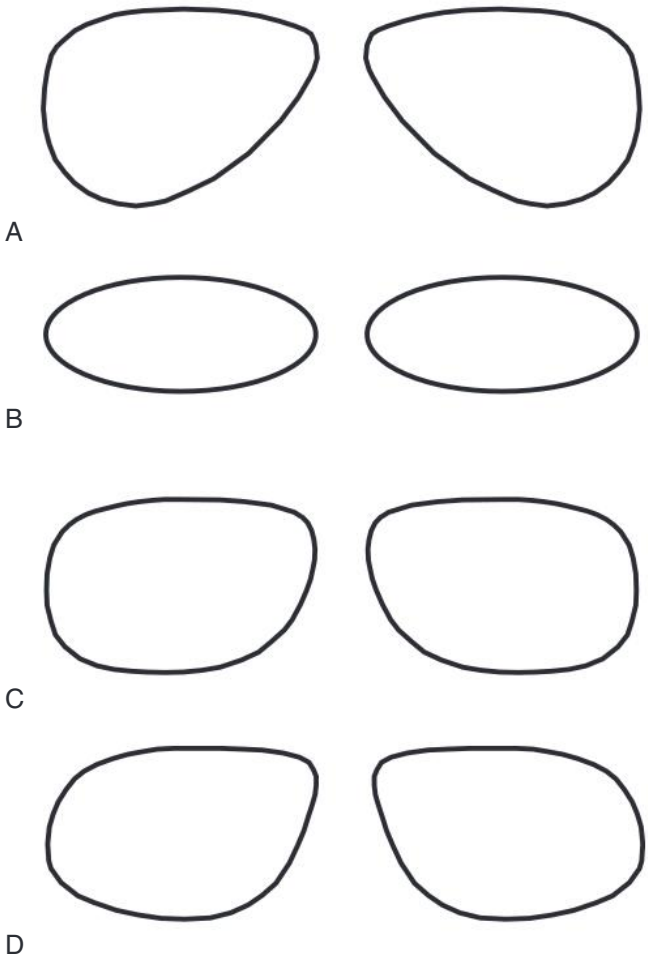

Figure 4.4 The best shapes for progressive addition lens wear have sufficient vertical depth and are not restricted in the inferior-nasal lens area. **A,** This frame choice is not a good choice for progressive lenses. This is because the area nearest the nose is where the progressive lens near zone is located. If this is cut away because of the shape of the lens, much of the near viewing area is removed. The aviator-style-shaped lens shown here in **A** is a classic example. **B,** This frame shape will work for a progressive lens if the lens style chosen is designed for frames with a narrow vertical dimension. This type of progressive lens is called a *short corridor progressive*. A frame with a narrow vertical dimension should not be used with standard-style progressive lenses. **C,** The best frame style for progressive lenses is one that has enough vertical depth to allow full use of both intermediate and near viewing areas of the progressive lens. **D,** Although not always cosmetically appropriate, a frame with a generous inferior-nasal lens area is optically ideal for a progressive addition lens.

- A good frame shape for a progressive lens has a *sufficient vertical depth and not much nasal cut* (see Figure 4.4, *C*).
- The best design for a progressive addition lens is one that has extra vertical depth in the inferior nasal portion of the shape (see Figure 4.4, *D*). Unfortunately, style and function do not always agree.

Selecting Frames for the High Minus Wearer

Although lenses are usually chosen for optical appropriateness, the cosmetic effects of certain types of lenses also should be considered. These lenses are at the extreme powers of minus or plus, which notably minify or magnify the eyes and face behind them. Several cosmetic factors must be considered when fitting the high minus correction wearer (Box 4.1).

Size

Size considerations include avoiding frames with lenses that are very large, since the lens edge gets thicker farther away from the center. Frames with rounded corners should be used when possible because squared-off corners are farther away from the center of the lens. A good indicator that a frame is too large is noticing that the eyes are positioned further away from the center of the middle of the lens shape than would be expected. In this case, the optical centers of the lenses will require excessive decentration.

A frame wider than the wearer's face at the temple area should also be avoided, since high minus lenses make the side of the wearer's head look narrower through the lenses (Figure 4.5).

BOX 4.1 Fitting the High Minus Wearer

Use	Avoid
Smaller eye size	Large lenses. (Especially avoid frames that extend beyond the sides of the wearer's head.)
If in between sizes, use the smaller indicated eye size and larger indicated bridge size	Excessive decentration
Rounded corners	Squared-off corners
Low-density (light-weight) lenses if weight reduction is important	Crown glass lenses
Mid-index or high-index lenses, such as polycarbonate or high-index plastic	Low-index lenses, such as CR-39 plastic lenses
"Hidden" bevels with a flat or angled ledge	Full V bevels
Well-smoothed, polished, or rolled and polished edges	Nonsmoothed or nonpolished edges, causing a concentric-ring appearance
Use plastic frames with rims that hide lens edges, and use a bevel placement that helps conceal lens thickness. (This is appropriate when not using lenses with smoothed, polished, or rolled and polished edges.)	Thin rims in combination with lenses having nonsmoothed or nonpolished edges
Antireflection (AR) coating (A light tint will help some, but an AR coating works better.)	Flat, non-AR-coated front curves
Aspheric or atoric lenses	
For exceptionally high minus—biconcave or minus lenticular lenses	

For high minus powers, the lens should be as small as possible to reduce thickness and weight. Suppose we could choose either a 48□20 or a 50□18 frame. Both will have the same width on the face because both eye and bridge sizes add up to 68 mm. We want to use the smaller eye size. Therefore, we will choose the frame with the wider bridge size. This allows the use of the smaller eye size. (If necessary, in order to assure a good fit, the nose pads can be brought closer together.) Why could a smaller eye size be helpful? For high minus lenses, using a 48-mm eye size instead of a 50-mm eye size will cause a measurable reduction in the weight of the lenses. Two 48- mm lenses will have both less weight and less edge thickness than two 50- mm lenses.

Lens Material

High-index plastic lenses are an excellent choice for high minus lenses. Lens edges will be thicker when made from lower-index CR-39 plastic. Using a lens of a higher-index material will reduce the edge thickness. Given equal lens center thicknesses, the higher the index of refraction of the material, the thinner the lens will be.

Polycarbonate lenses offer both a weight and edge thickness advantage over conventional CR-39 plastic. Polycarbonate and Trivex lenses can be made with a thinner center thickness because of their high-impact resistance. This translates into a thinner edge. Even if a polycarbonate lens has the same center thickness as a regular plastic CR-39 lens, the edge of the polycarbonate lens will still be thinner than the CR-39. This is because polycarbonate's index of 1.586 and Trivex's index of 1.532 are both higher than the CR-39 index of 1.498. (For more information on lens materials, see Chapter 23.)

Reflections, Base Curve, and Lens Bevel

Reflections, *curve*, and *bevel* are additional considerations. The larger the bevel, the more reflection rings will be noticeable because these rings are a reflection of the lens edge. Using a hidden bevel as shown in Figure 4.6, *B* (rather than the older 40-degree bevel as shown in Figure 4.6, *A*), reduces the problem somewhat. Newer edgers can produce a mini-type bevel with a more angled ledge and smoothed nicely with excellent results (see Figure 4.6, *C*).

Figure 4.5 High minus lenses minify objects. When high minus lenses are worn in a frame that is too large, the observer sees the wearer's face minified through the lenses. This makes the head look narrow in the area behind the lenses compared with the rest of the face.

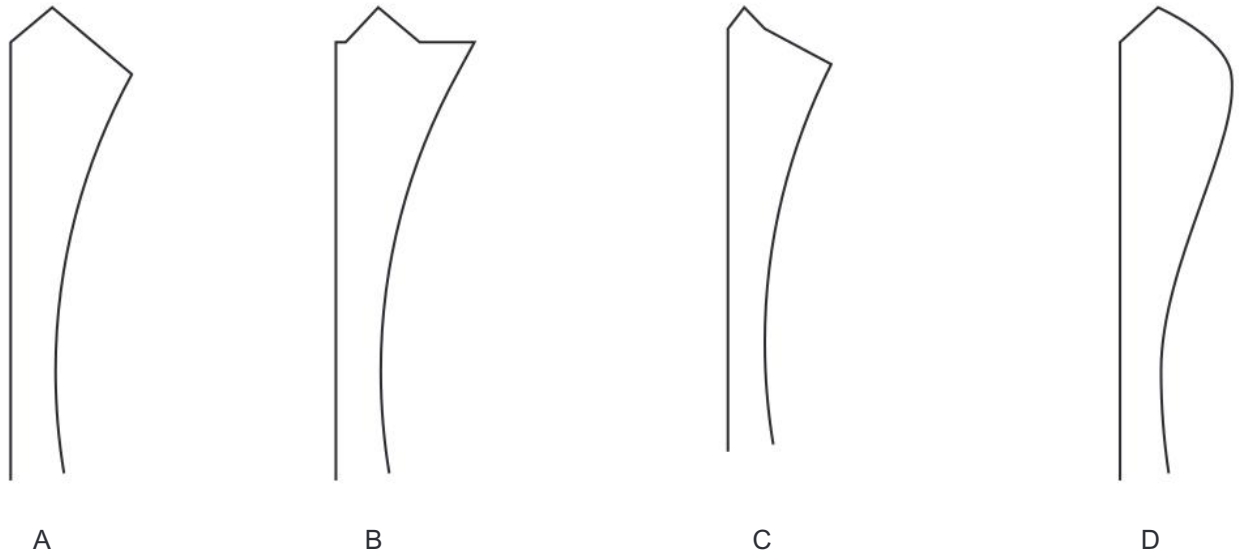

Figure 4.6 **A,** An older-style 40-degree bevel is inappropriate for a high minus lens. Fortunately, it is almost never used. **B,** A flat bevel reduces some of the internal reflections and concentric rings that would otherwise be seen with a regular 40-degree bevel. However, the edge will still appear thick. **C,** A mini-bevel configuration with a smaller bevel and a more angled edge than the flatter edge shown in **(B)**. **D,** A rolled and polished bevel reduces edge thickness.

The edge of a high minus lens can be made less noticeable by *rolling the edge*. This is especially true for metal or thin plastic frames. Rolling the edge changes the back ledge from flat to rounded, as shown in Figure 4.6, *D*. This gives a nice appearance to the lens and often reduces measured edge thickness by as much as 2 mm. *Polishing the edges* will make the lens look better to an observer. However, unless an antireflection (AR) coating is used, such polishing will introduce internal lens reflections, which are disturbing to many wearers. Although the combination of *roll and polish* looks very good, some recommend using a roll and polish with caution because of the possibility of wearer dissatisfaction due to the distortion caused by the rolled area in the periphery of the lens. An edge does not have to be rolled to be polished. A conventionally beveled lens edge can also be polished. With better manufacturing techniques, polished edges are much easier to produce and are coming to be expected on lenses with visible bevels.

Unless AR coated, a *front curve* reduced below +2.00 D will result in a high reflection of light from the front. Unfortunately, high minus lenses made with ordinary spherical curves require a fairly flat front curve to give good optics. It is possible to use an aspheric design to allow for a different front curve and to slightly thin the edge of the lens by steepening the lens in the periphery. An aspheric high minus lens may have a better cosmetic appearance than a conventional, spherically based lens of the same power. (For more information on lens design and aspherics, see Chapter 18.)

Even though a light tint will reduce internal lens reflections, an AR coating does a much better job. Even lenses with flat front curves will lose their mirror-like reflective appearances with an AR coating. AR coatings also eliminate the concentric rings, which are frequently seen with high minus lens prescriptions.

For wearers with excessively high minus lenses, a minus lenticular design is an option. (For more on the subject, see Chapter 18.)

Miscellaneous Factors

An interesting consideration is that high minus lenses tend to cause eye *makeup* to show up less, whereas high plus lenses cause any type of makeup to be more noticeable.

Selecting Frames for the High Plus Wearer

Size and Thickness

Size and *thickness* are considerations with high plus lenses (Box 4.2). Large lenses should be avoided because of excessive weight and the increase in center thickness. High plus lenses magnify the wearer's eyes. When lens size increases, so does center thickness, causing an even greater magnification problem.

Because of differences in frame shapes, frame eye size (the A dimension) is not the only influence on lens thickness. The ED of a lens is increased whenever a lens deviates from a round or oval shape. The more the lens deviates from round or oval, the thicker the lens will be (Figures 4.7 and 4.8). A good rule of thumb for very high plus lenses is to avoid frames with an ED more than 2 mm larger than the eye size.

BOX 4.2 Fitting the High Plus Wearer

Use	Avoid
Smaller eye size	Large lenses
Rounded lens shapes	Unusual shapes and long corners
Lenses with effective diameters (EDs) no larger than the eye size +2 mm	Lenses with EDs greater than the eye size +2 mm
Shapes with small "frame differences"	Shapes with "frame differences" that are greater than 9 mm
Sturdy construction	Flimsy construction
Short vertex distances	Large vertex distances
Adjustable (nose pad) bridges	Fixed bridges
Cable or securely fitting temples	Library and straight-back temples
High-index plastics	Glass and CR-39 lenses
AR Coatings	Nylon cord frames
Aspheric or atoric designs	Normal, spheric designs (Above +7.00 D nothing works well optically except aspheric)

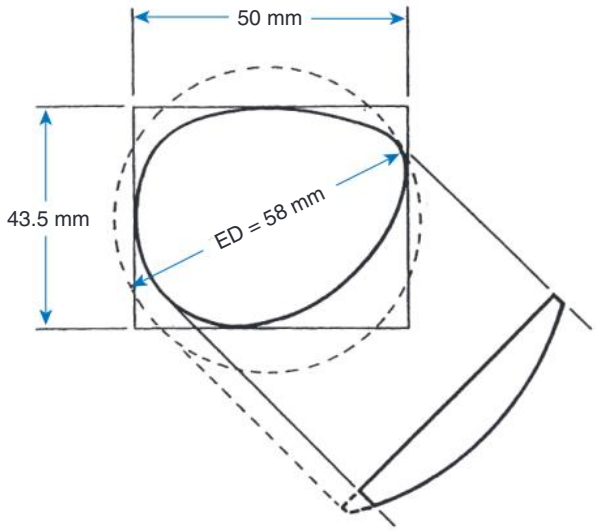

Figure 4.7 The larger the effective diameter (ED) of a plus lens for a given eye size, the thicker the edge will be in certain meridians. Because a larger lens blank size is required, the center thickness will also be greater.

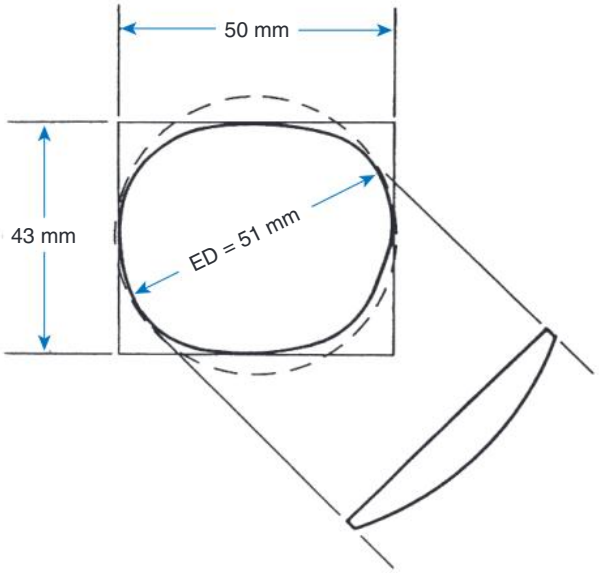

Figure 4.8 When the effective diameter (ED) is close to the frame eye size, the edge thickness will be more uniform and held to a minimum. Small EDs also make possible a lens of minimal center thickness. (For a further explanation of EDs, see Chapters 2 and 5.)

Frame Difference

"Frame difference" (see Chapter 2) is an additional factor when selecting a proper frame shape for the high plus wearer. Frames with vertically narrow lens openings (where the difference between horizontal and vertical measurements is large) cause a high plus lens to be thick on the top and bottom edges (Figure 4.9). This causes the strong plus lens to look even stronger. For the high plus lens wearer, frame differences greater than 9 mm should be avoided.

Cataract Lenses and UV Protection

Cataract lenses are very high plus lenses that were used after cataract surgery before the advent of intraocular lens implants. They are now rare. Cataract lenses usually range in power from +9.00 to +22.00 D, depending upon the wearer's lens prescription before surgery. The prescription was this high because it had to replace the power of the crystalline lens of the eye that was removed during surgery. Fortunately, the crystalline lens is now replaced with a small lens implanted into the eye. People who have had cataract surgery and have not received an intraocular lens implant are aphakic (which means "without lens"). They are referred to as *aphakes*. Aphakes must either wear contact lenses or high plus cataract spectacle lenses. Fortunately, intraocular lens implants are now the standard for cataract surgery, making such situations quite uncommon. (Those who have had cataract surgery and have an intraocular lens implant are called *pseudophakes*.)

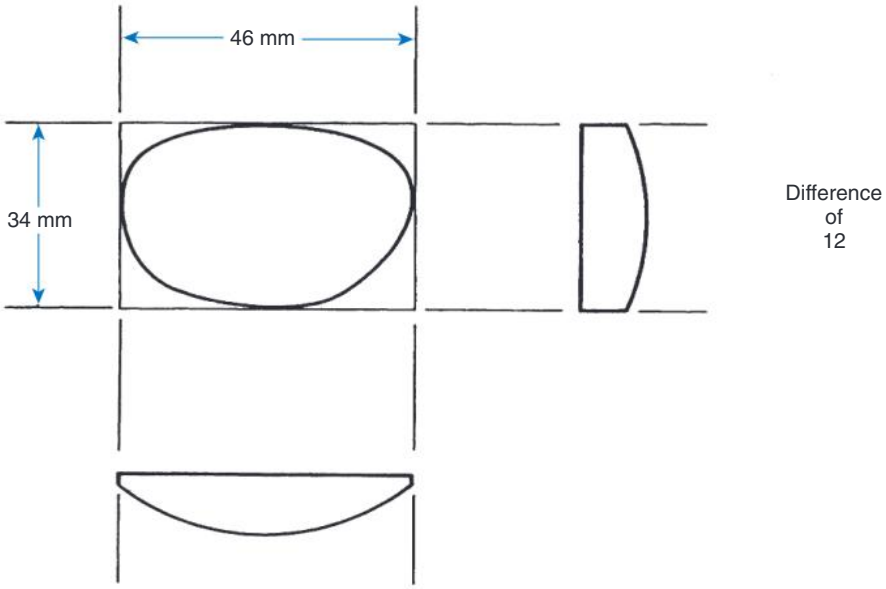

Figure 4.9 In the case of the high plus lens, the larger the frame difference, the thicker the lens will appear on the top and bottom. The case is reversed with the high minus lens, however, since the thicker edges will then be in the horizontal meridian.

Aphakes are often more light-sensitive than other individuals as a result of crystalline lens removal. To prevent damage to the retina of an aphakic individual caused by *UV light,* protection is essential. Only spectacle lenses with UV-inhibiting properties should be used for aphakes. Even then, UV light entering from the side can still be damaging. (For more information on UV protection, see Chapter 22, *Absorptive Lenses.*)

Frame Characteristics

There are certain frame characteristics that are necessary for properly fitting high plus lenses. With medium power plus lenses, these characteristics can be considered as suggested guidelines, but with high plus or cataract lenses, they are mandatory prerequisites.

Frames should be chosen for their ability to hold their *alignment.* Flimsy construction allows the lenses to slide down the nose. This is not only irritating to the wearer, but it also has some rather serious optical side effects. These include:

1. The blurring of distance vision because of a change in effective lens power.
2. A smaller field of view.
3. An increase in the magnification of objects viewed by the wearer.
4. An increase in the apparent size of the wearer's eyes to an observer (Figure 4.10); as the vertex distance decreases for plus lenses, the wearer's eyes look less magnified when viewed by an observer.

A frame should be chosen that allows the distance optical center of the lenses to be positioned properly before the eyes. See Figures 4.11 and 4.12 for further explanations.

Because field of view is increased and magnification decreased as plus lenses are moved closer to the eyes, the frame selected should hold the lenses as close as possible to the eyes. The wearer's eyelashes should just clear the back surfaces of the lenses.

Nylon cord frames should be avoided. The thinnest edge will need to be made thicker than for other frames to allow enough thickness for the lens edge to be grooved. If the thinnest edge is made thicker, the whole lens must be made thicker.

Adjustable nose pads become more of a necessity as the power of the lenses increases. They offer the advantage of versatility in allowing the height of the frame to be adjusted. This allows the major reference point height, bifocal height, or progressive lens fitting cross height to be more exactly adjusted.

Adjustable nose pads also allow the lenses to be positioned at varying distances from the eyes. This allows more precision in the refractive power of the correction. Unless a high-powered lens is fitted at the refracting distance used during the eye examination, an error in power will result. Unless a compensation for the vertex distance change is made, significant error results. For example, if a +15.00 D lens is intended for a 12- mm vertex distance between the cornea and rear lens surface but were to be fitted at 17 mm, the lens would be almost +1.25 D too strong. It is obvious then that, with high-powered lenses, power compensation for variations in vertex distance is a necessity for bridge designs not using adjustable pads. (For how vertex distance power compensations are done, see the *Effective Power* section in Chapter 14.)

Serious consideration should be given to using *comfort cable temples* when the anatomic features of the nose do not lend themselves to keeping the glasses in place or if the prescribed glasses tend to be somewhat heavy. Cable temples help keep the glasses from slipping down the nose and, thus, help avoid the difficulties listed above.

Selecting Frames for Children

When selecting frames for children, safety should be the first concern. Children are always doing things that are unexpectedly hazardous, and children's eyeglasses can be expected to endure much abuse. The main

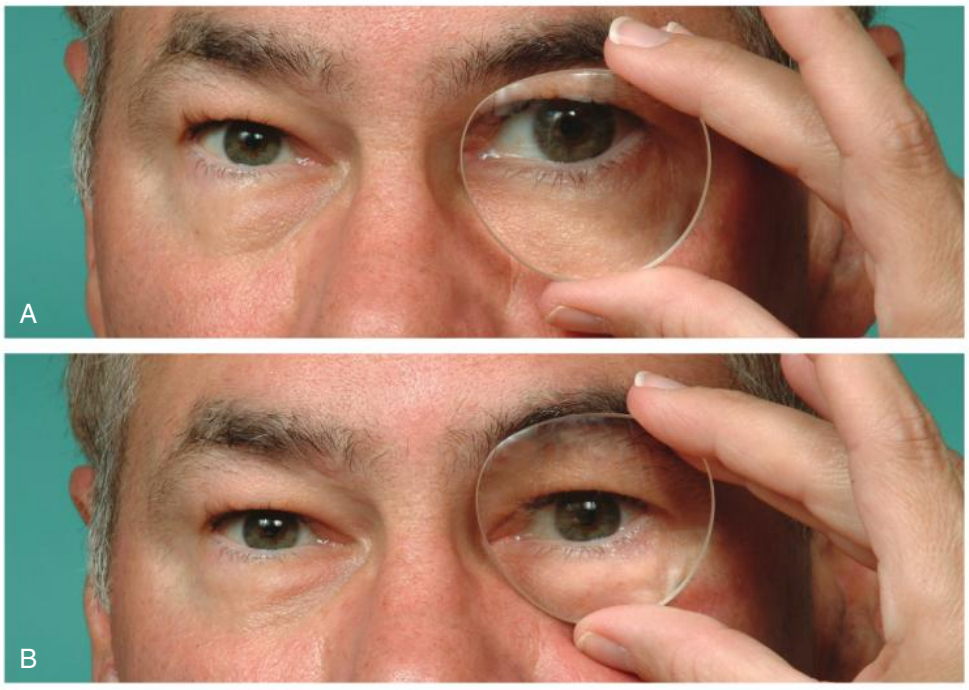

Figure 4.10 The lens in **(A)** is positioned with a large vertex distance, whereas in **(B)** the vertex distance is minimal. The same lens was used in both photographs, which were taken under circumstances that were as identical as possible. The only difference between the two photographs is the distance from lens to eye. In both cases the eye is magnified, as can readily be seen by comparing the eye behind the lens with the eye without the lens. However, the eye behind the lens in **(B)** shows less magnification than the eye behind the lens in **(A).**

Figure 4.11 To avoid adversely affecting the optical performance of the lens, for every millimeter that the optical center is below the wearer's line of sight, there should be 2 degrees of pantoscopic tilt. For example, as pictured here, the optical center falls 4 mm below the lenses, requiring 8 degrees of pantoscopic tilt in relationship to the plane of the face.

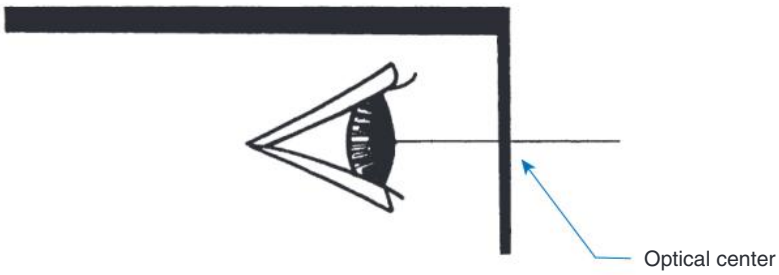

Figure 4.12 When the pupil corresponds to the optical center of the lens, there should be no pantoscopic tilt. Any lens tilt added will change the sphere power of the lens and cause an unwanted cylinder component to be manifested. For low power lenses, the power-change effect is negligible, but with a higher power lens it can be quite evident. (For further explanation, see Chapters 5 and 18.)

concern is not so much that the frames and lenses hold up to such abuse but rather that the child is not put at risk because of a poorly chosen frame.

Remember, a frame that is small and sold for children may not necessarily be the best design for children. Because style is important to children too, children's frames often mimic adult styles.

Children's frames should be sturdy. Look for solidly built frames, be they plastic or metal. The grooves in the frame to accept the bevel of the lenses should be deep so that the lenses are more securely seated in the frame.

It is advisable to avoid nylon cord frames because the thin cord may not hold the lenses in place securely enough for rough-and-tumble play.

When available, high-quality spring hinge temples are a good option. When hit from the side, the spring takes much of the shock, instead of transferring all of it to the side of the nose. In addition, spring hinge temples will save trips back to the dispensary to have the frames realigned.

Although not directly related to the subject of frame selection, it is important to note that polycarbonate lenses or Trivex lenses are the lenses of choice for children. The increased safety far outweighs any considerations. In short, children need high-impact-resistant lenses, and dispensers have a responsibility to make sure that parents know why.

Both polycarbonate and Trivex lenses have the added benefit of giving children UV light protection at no additional cost. The crystalline lens of a child's eye will let more light through than will the lens of an adult. UV light can begin to take its toll early in life, so it is never too early to begin protection.

If a child leaves the dispensary with lenses other than high-impact lenses, the record should contain a dated statement noting that the parents were informed of the advisability of using such lenses and refused that option. A form to that effect signed by a parent is a further precaution against liability but is not a legal requirement. (For more on the issue of liability, see Chapter 23.)

With an increased emphasis on sports for children, specialty sports glasses should not be overlooked. Children who participate in sports such as baseball may be at greater risk than adults who play the same sport. Not all children can react quickly enough to avoid a ball in the eye. Carelessness by other children when throwing balls or swinging bats also adds to the risks. A conscientious dispenser will be aware of options in sports eyewear for children and make them available. (For more on sports eyewear, see Chapter 23.)

Box 4.3 provides a summary of factors in selecting frames for children.

Selecting Frames for Older Wearers

When selecting frames for older wearers, perhaps the most important factor to consider is weight. With age, the skin loses its elasticity. This causes nose pads to depress the skin and underlying tissue, leaving marks that do not rebound easily. When the eyeglasses are heavy, red marks on the nose and ears can easily develop into sores that are slow to heal. Therefore, choosing a frame that is lightweight and combining that selection with a lightweight lens material will do much to prevent problems.

BOX 4.3 Frame Selection for Children

Use	Avoid
Sturdy frames	Lightly constructed copies of adult frames
Deeply grooved frame fronts	Frames with shallow grooves
Quality spring hinge temples	Nylon cord frames
Bridges that give support in the area of the lower portion of the nose pad	
High-impact lenses such as polycarbonate or Trivex	Any lenses that are not highly impact resistant; especially glass lenses
Sports protection when applicable	

The bridge of the frame must fit correctly. If the bridge fitting principles that were explained earlier in the chapter are exactingly applied, the frame will be comfortable. Remember, with older wearers there is less room for error. The bridge must seat itself over the largest area possible to evenly spread the weight of the glasses. For this reason, when selecting a frame with adjustable nose pads, consider whether the pad size will be appropriate for the weight of the frame.

Unless the wearer has no distance prescription, the shape of the frame must leave enough room for the type of multifocal design selected. (See the section in this chapter on selecting frames for progressive addition lens wearers.)

It should not be assumed that the older wearer will be unconcerned with style or will only be interested in the same type of frame as they have been wearing. Older individuals are to be accorded the same frame styling options given everyone else.

Selecting Frames for Safety Eyewear

Safety frames are no longer limited to drab colors and "S7" safety frame shapes; they are available in a large variety of styles. In many cases they are not easily distinguished from regular "dress" eyewear. Although function is paramount, rules for selecting a well-fitting, nice-looking frame do not change dramatically when selecting safety eyewear.

Remember that a safety frame is not just a sturdy frame with thicker lenses. A safety frame intended for prescription lenses must comply with specific standards and be identified with the mark "Z87-2" on both the temples and the frame front. The number "2" indicates that the frames have passed impact requirements with mounted lenses that are as thin as 2 mm.

Metal frames should be avoided when electrical hazards are present, and side shields are necessary when eye injuries from the side are possible.

There are several factors other than the fit of the frame and the few obvious considerations listed here that must be taken into account when dispensing safety eyewear. Therefore before ordering, it would be advisable to review the appropriate section on the subject found in Chapter 23.

Devices That Help in the Frame Selection Process

The problem of helping with frame selection for the person with poor, uncorrected visual acuity is less now than it used to be. The device that made the biggest difference was the smart phone with its integrated camera. Individuals can take their own selfie from a variety of angles or have someone else take the pictures.

The next step is to have a tablet device in the dispensary that gives larger images than the smaller cell phone screens. This tablet may not have any other secondary purpose, or it may be one that incorporates a fitting and dispensing application. Such a fitting system may include:

- A side-by-side image comparison of more than one frame style or more than one viewing angle. Most systems allow up to four images on one screen.
- As with regular tablets, a video capture option is available.
- A demonstration of what the world may look like through various types of lenses. Examples could include:
  - different types of progressive addition lenses
  - photochromic or polarizing lenses
  - AR-coated lenses
- Some may have an "augmented reality" option that shows a view of objects inside or outside the office.These show how the lens being demonstrated may affect the way the world might look through that particular style of lens.
- Some allow the fitting parameters to be measured by the system, such as
  - Monocular distance PDs
  - Monocular near PDs
  - Multifocal segment heights
  - Progressive lens fitting cross heights
  - Vertex distance
  - Pantoscopic angle
  - Frame wrap angle (face form)
  - Objective frame measurements such as A, B, ED, and DBL (which may or may not exactly agree with all marked frame measurements)
- Most of these systems will require a clip-on with reference points to be attached to the frame front.

There are more complex table-top of self-standing units uniquely suited for specific lens types and product demonstrations. Prices on these and the tablet-based systems can vary considerably.

Closing the Frame Selection Process

Selecting a frame is a decision-making process, and making decisions is difficult. A good dispenser can help in making that process easier. Here are a few suggestions.

1. Do not prejudge a person's financial situation by only showing less expensive frames. Let each person make his or her own decision on how much to spend.
2. Do not voluntarily categorize a person's face as being a certain shape for them. They may not agree with you. Be diplomatic.
3. Do not insist on a certain frame if the wearer does not like it, even though it may look best and be optically sound.
4. Do not allow the wearer to select a frame or lens style that you know would be unsafe or optically unsound.
5. Do not have a large number of frames spread out at any one time. People forget what they have looked at and rejected. Too many frames out at once may cause a person to become confused or overwhelmed. If a frame choice is unsatisfactory, return the frame to the display or put it out of sight. Try and keep the number of frame styles being considered at three or less at any given time.
6. Do not ask "if"; ask "which." Presenting procrastination as a possible alternative is a disservice to those who find the decision-making process difficult. Helping to narrow the choice to two possibilities simplifies matters.
7. Do not overlook the possibility of more than one pair. In many cases one pair is not enough. Some people want or need more than one pair because:
   a. They like both and can afford both.
   b. They need a backup pair and know it.
   c. Their visual needs vary in different work situations.
8. Be sure to point out the positive aspects of the frames that are being considered. People want to know they are buying an appropriate, quality product. The typical wearer of eyeglasses usually knows very little about frames and lenses. Telling the wearer why these frames and lenses are good will help them to feel confident in their decision.

A WORD ON FRAME MANAGEMENT

Good frame selection is based on the availability of a variety of quality frames in the dispensary. No matter how many frames are on the frame boards, if those frames are all the same style, the frame selection process will not lead to a successful outcome. The person responsible for buying frames needs to be aware of the various types of individuals who will be selecting frames and choose frames to buy with that in mind.

Left alone, frame inventory will most certainly obey the Second Law of Thermodynamics and go from order to disorder. Below are a few examples of what can happen with frame inventory in the dispensary. The solutions given are not limited just to the example stated, but they are generally applicable to the dispensary.

Example 4.1. Too Many "Dogs"

People seem to be having an increasing hard time finding frames they like. The staff has trouble helping them. It seems that most of the frames are just not very appealing. What went wrong?

Solution

The person buying frames buys a logical selection of frames. Some frames sell immediately. Unfortunately, they are not reordered. The ones that were not popular do not sell and stay on the board. Another frame representative arrives and the same scenario is repeated. Before long the dispensary has an overwhelming number of frames that nobody really wants.

To prevent this from happening, keep a log of which frames are selling and replace those frames immediately. If a frame requires a long time to sell, do not replace that frame when you sell it unless it is in the dispensary to serve a certain type of clientele. It is advisable to consult with your frame representatives as they know what frames are selling in your area.

Example 4.2. Some Find Frames Easily; Others Cannot Even Get Started

Unlike the previous situation in which it is difficult to find the right frame, in this situation frame selection is frustrating with some people, but not everybody. It is not just wearer indecision. The staff has trouble helping certain individuals find something that looks right for them, too.

Solution

When a frame representative comes into the office, there are one or two of the staff who looks over the new available frames, trying to decide what to buy. In the process, the staff tries on the frames to see what looks good. As a result, over time the dispensary is filled with frames that look great on the staff, who may have one facial type or one particular taste in style. People with other fitting characteristics are unable to find frames that are appropriate for them.

To keep the inventory balanced, the buyer needs to think about what is necessary for different facial types and different tastes in frames, such as conservative versus trendy.

Example 4.3. Back-Stock Drawers and Cabinets Are Full

Every dispensary has some place where extra frames are stored. There should be a limited number of frames in back stock. In this case, however, every drawer is full. What happened?

Solution

There is more than one reason why this situation could occur. The proper contents of these storage areas are backups for frames that are moving very quickly. If all of the stored frames are discontinued or frames that just will not move, then Example 4.1 above has been "solved" by removing the "dogs" from the board and ordering new frames. Here is an example of what can be happening if backups are not in this category.

Frame companies often have promotions. With a certain sized order, the company may give away a "premium." This could include such things as trips, watches, or computer-related prizes. If the buyer finds these things desirable, it does not take long to end up with too much stock. Do not buy frames just because they come with rewards.

Example 4.4. Everything Is Discontinued

You have picked out just the right frame, but the color is wrong. You try to order the needed color, but the frame has been discontinued. Unfortunately, this is becoming a regularly occurring problem. What is wrong?

Solution

Some discontinued stock is unavoidable. But when the issue just keeps growing, there is a problem somewhere. Here are some typical causes and/or solutions. Most of them are just generally good practices for responsible frame management.

1. You may be buying frames from too many places. Having too many companies will make it difficult to track what is really happening with frame sales. Use a limited number of frame companies and know your representatives well. If you are not a large account for anybody, then your individual frame representatives do not have much of an interest in seeing that your frames are up-to-date. If you know your frame representatives and they know you, it should be in their best interest to work with you for the long-term benefit of your dispensary.
2. If you receive a notice that a frame is to be discontinued, act now. You have a limited time to return it for credit. Do not miss that time. If you miss the cut-off, how to get rid of the frame is your problem.
3. Be careful of "deals" in which you can get a large number of frames for a very low price. Those frames may be scheduled to be discontinued or may already be discontinued.
4. Before you bring a new frame company "on board," ask about their return policy. Tell the representative of that company that you expect them to keep you informed of frames that are to be discontinued.
5. Allocate a frame representative from a certain company a certain given number of spaces on your frame board. Let them know that it is their responsibility to work with you to keep those frames current and moving. It will be in their best interest to determine which frames sell best in your practice and which do not. They will not want any discontinued frames taking up space in their area.
6. Although it is good practice to immediately reorder frames that are selling quickly, it is not good practice to automatically reorder everything. If a frame is not selling, do not reorder when it does sell. If you notice that a frame is not moving, do not wait to exchange it.
7. If the problem exists already, try to recover without just moving mountains of discontinued frames into a "spare parts" box. Figure out ways to move stock that has not sold, is not returnable, and may still have value. Here are some ideas: Mark it down. Put plano sunglass lenses in the frame and sell them at an attractive price. If there are some frames that still will not move, donate them to a charitable organization.

REFERENCES

1. Many of the factors listed in this section are from the following brochure: Cook P: Should I use my old frames, Item No. BRO011, 1999, Diversified Ophthalmics.
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PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. According to conventional frame selection principles, which frame characteristic is most appropriate for a person with an oblong face?
   a. A vertically narrow frame
   b. A rimless frame
   c. A vertically deep frame
   d. A frame with a high temple attachment
2. According to conventional frame selection principles, which frame characteristic is more appropriate for a person with a round face?
   a. A rimless frame
   b. A vertically deep frame
   c. A frame with a low temple attachment
   d. A large, dark, bold frame
3. According to conventional frame selection principles, which frame characteristic is more appropriate for a person with an inverted triangular (base-up) face?
   a. A frame with darker colors or a bolder look
   b. A rimless or thin-rimmed frame
   c. A vertically deep frame
   d. A frame with a low temple attachment
4. According to conventional frame selection principles, which frame characteristic is more appropriate for a person with a base-down triangular face shape?
   a. A frame with darker colors or a bolder look
   b. A rimless or thin-rimmed frame
   c. A frame with a low temple attachment
   d. A frame with temporal vertical lines that tilt outward temporally in the lower portion of the frame
5. Which of the following is indicated and should be used when fitting the high minus lens wearer?
   a. rounded corners
   b. large lenses
   c. 40-degree V bevels
   d. crown glass lenses
   e. excessive decentration
6. Which face shape most lends itself to wearing glasses?
   a. the wide face
   b. the long face
   c. the base-down triangular face
   d. the base-up triangular face
   e. the diamond face
7. Which of the following would be an example of a frame appropriate for a wide face?
   a. a frame with a large difference between horizontal and vertical measurements
   b. a frame on which the temples attach low on the frame
   c. a frame in which the lenses are deep, covering a larger facial area
8. According to conventional frame selection principles, when deciding upon the upper frame line design,
   a. it is desirable to choose an upper eyewire line that follows the basic line of the eyebrow.
   b. it is best to choose an upper eyewire line that contrasts with the eyebrow line somewhat.
   c. the best design is one that starts below the eyebrow, crosses the eyebrow at the midpoint, and continues on above the eyebrow.
9. True or false? Choosing the favorite or dominant color a person wears for their frame color should be avoided, since the color repetition calls too much attention to the glasses.
   a. True
   b. False
10. True or false? A lighter-colored, more delicately styled frame is recommended for the person with light, fine hair.
    a. True
    b. False
11. True or false? Individuals with salt-and-pepper hair or hair that is just starting to gray will find that choosing a silver frame will make the "salt" component of their salt-and-pepper hair more noticeable and should be routinely avoided.
    a. True
    b. False
12. True or false? When in doubt as to which frame weight to choose, select the heavier weight frame.
    a. True
    b. False
13. The lower the frame bridge, the greater the effect of:
    a. shortening of the nose.
    b. lengthening of the nose.
14. Which of the following is *not* an important criterion in choosing a frame for a progressive addition lens wearer?
    a. a minimal vertex distance
    b. adequate pantoscopic tilt
    c. sufficient vertical depth in the nasal portion of the frame shape
    d. All of the above are important criterion when choosing a frame for a progressive addition lens wearer.
15. Which of the following should be *avoided* when fitting a high minus wearer?
    a. a high-index lens material
    b. squared-off corners
    c. aspheric lenses
    d. smaller eye size
    e. an AR coating
16. Which lens or frame characteristic should be avoided when selecting eyewear for a +6.00 D lens wearer?
    a. Frames with adjustable pad bridges
    b. Lenses with EDs greater than eye size +2 mm
    c. Cable temples
    d. Frames with "frame differences" of less than 9 mm
17. Which of the following is *not* a good frame characteristic for a person having a high plus lens prescription?
    a. small lens size
    b. adjustable bridge
    c. library temples
    d. high-index lenses
    e. as rounded a lens shape as possible
18. With high plus lenses, should **more** or **less** eye makeup than average be used for an equal cosmetic effect compared with what would be worn without spectacle lenses?
    a. more
    b. less
19. To check bridge size, lift the frame very slightly from the nose and move it to the left or right. There should be about _____ mm of clearance between the nose and free side of the bridge.
    a. 0.5
    b. 1.0
    c. 1.5
    d. 2.0

20. What is the best way to reduce ring reflections in a high minus prescription?
- **a.** use a smaller lens size
- **b.** use a higher index material
- **c.** tint the lenses slightly
- **d.** have the lab polish the lens edges
- **e.** use a dark-colored frame
- **f.** use an AR coating on the lenses

21. Of the frame characteristics listed below, which is the *least* desirable for children?
- **a.** deeply grooved frame fronts
- **b.** nylon cord frame construction
- **c.** spring hinge temples

22. True or false? Rules for selecting a well-fitting, nice-looking frame change dramatically when selecting safety eyewear.
- **a.** True
- **b.** False

23. True or false? When buying frames for the office, one of the fastest and best ways to choose frames is for the staff to try them on.
- **a.** True
- **b.** False

24. It becomes evident that there are a great many frames on the board that are discontinued. Which of the following is *least* likely to be a contributing factor to this unfortunate situation?
- **a.** All frames are automatically reordered when they have been sold from the board.
- **b.** Large numbers of frames are being purchased at low-cost special prices.
- **c.** Frames are being purchased from a large number of sources.
- **d.** Frame representatives have been allocated a given number of board spaces and come in on a regular basis to check on how their frame product is moving.

25. A certain lens pair has plus powers of +5.75 D, O.U. The wearer has a PD of 64 mm. Here is a selection of frames. Assume that all frames fit fine and, during frame selection without the lenses, look OK. Considering only the cosmetic and weight aspects of resulting lens center and edge thicknesses, rank these frames from the best frame choice to the worst frame choice for this plus lens prescription.

1. A = 55, B = 38, DBL = 20, ED = 59
2. A = 48, B = 41, DBL = 18, ED = 50
3. A = 46, B = 39, DBL = 20, ED = 48
4. A = 48, B = 34, DBL = 18, ED = 50

- **a.** 1, 2, 4, 3
- **b.** 3, 4, 2, 1
- **c.** 4, 3, 2, 1
- **d.** 3, 2, 4, 1
- **e.** 4, 2, 3, 1

5

Reference Point Placement, Multifocal Height, and Blank Size Determination

POSITION OF THE FRAME

If the frame is not properly positioned on the face for the initial measurements, both the frame and the lenses may not be in the correct positions when the frame is dispensed and properly adjusted.

With metal frames, the best policy is to adjust the nose pads to a correct angle and position before any measuring is done. This ensures a more correct lens fitting height and bridge size evaluation.

With plastic frames, it is fairly simple to evaluate the bridge size. If the bridge of the sample frame is too small, the frame will sit too high; if it is too large, it will sit too low.

OPTICAL CENTERING FOR SINGLE-VISION LENSES

Horizontal Placement of the Lenses in the Frame

When spectacles are made, the typical lens position has the *optical center (OC)* of the lens lined up with the pupil of the eye. The OC becomes the major point of reference for the lens. When light goes through the OC of the lens, it does not bend but travels straight through. If light does not travel through the center of a lens with power, the light will be bent. If light bends, there is a prismatic effect at that point, but at the OC of a lens, there is no prismatic effect.

Prismatic Effect

To avoid undesired prismatic effects, the OCs of the lenses are placed the same distance apart as the wearer's two lines of sight. This is why interpupillary distance (PD) is measured. The measurement techniques for finding the PD are covered in Chapter 3.

In some cases, a lens prescription calls for a certain amount of prism. The OC of the lens has no prism, so it will not be placed in front of the wearer's pupil. Instead, the patient will view through a point on the lens where the amount of prism is equal to that called for in the prescription. This new point on the lens is now the point of major importance. This major point of reference where the prismatic effect equals the prescribed amount of prism is called just that—the *major reference point* (MRP). Succinctly stated, *the point on the lens where the prism is equal to that called for by the prescription is called the* MRP.

Note that when there is no prism called for in the prescription, the OC and the MRP are at exactly the same point on the lens. They are one and the same. But when there is prescribed prism in the prescription, the eye no longer looks through the OC. In other words, with prescribed prism, the OC and the MRP are in two different locations. Stated simplistically, the line of sight of the eye passes through the MRP, whereas the lens OC is somewhere else.

Synonyms for MRP

There are other terms that are sometimes used in place of MRP.

1. The MRP is often referred to as the *prism reference point* or PRP. This is particularly true for progressive addition lenses.
2. When pertaining to a single-vision or a segmented multifocal distance lens prescription, the MRP may also be referred to as the DRP, or *distance reference point*. However, this is *not* the case for progressive addition lenses! (See Chapter 20, *Progressive Addition Lenses*.)

Prentice's Rule

The amount of prism experienced when the patient looks away from the OC of the lens can be calculated according to the power of the lens and the distance that the OC is displaced. It is calculated according to *Prentice's rule*, which states:

$$\Delta = cF$$

where Δ is prism diopters caused by the displacement, F is the dioptric power of the lens in the meridian of displacement, and c is the distance from the center of the pupil to the OC of the lens in centimeters.

For example, if the lens power is +2.00 D and the OC varies from the wearer's interpupillary reference point (usually the center of the pupil) by 6 mm, the induced prism will be:

$$\Delta = 0.6 \times 2.00 = 1.2$$

The base direction of the prism for plus lenses is toward the center of the lens. The base direction for minus lenses is toward the edge of the lens.

Face Form

There is also a relationship between the placement of the OCs in the frame and the extent to which the curve in the frame front varies from the classical four-point touch position (see Chapter 8 for an explanation of four-point touch). This curve in the frame front is often referred to as *face form*, because the frame front more closely conforms to the curve of the face. A synonym for face form is *wraparound*, or simply *frame wrap*.

This curve serves both the cosmetic purpose of improving the frame appearance and the optical purpose of properly aligning both front and back surfaces of the lenses so that the wearer's line of sight is perpendicular to both the front and back surface of the lens. (Remember, at the OC of the lens, front and back surfaces are parallel to one another.)

If the wearer's PD equals the frame PD (eye size plus bridge size), then no face form is required; the frame front should be straight (Figure 5.1).

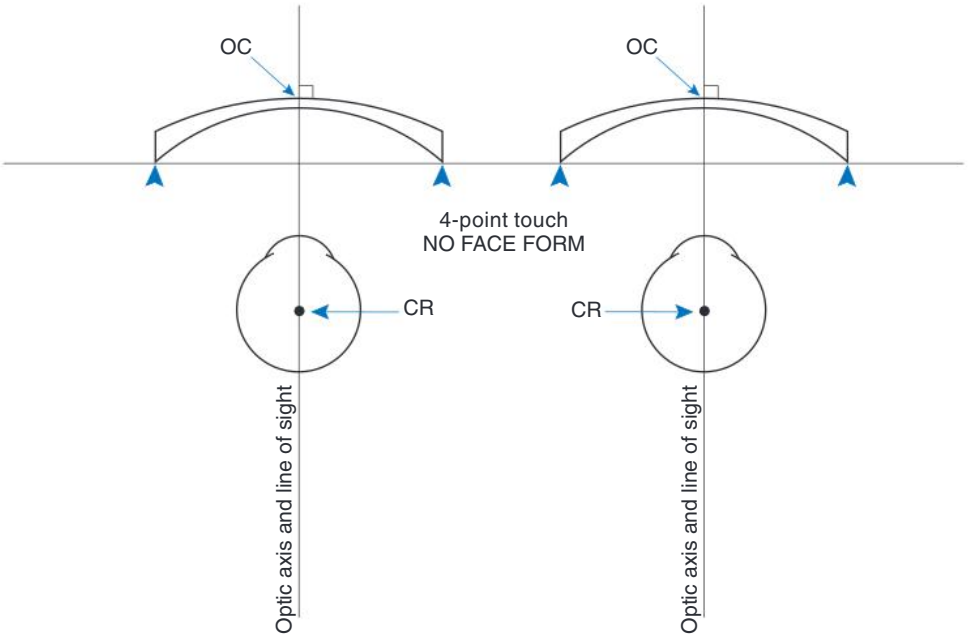


Figure 5.1 When the optical centers (OCs) of the lenses are at the horizontal center of the frame's lens openings, the geometric center distance (frame PD) equals the wearer's interpupillary distance (PD). The lenses should have no face form (a four-point touch). When this is the case, the optic axis and line of sight are the same. Light entering along the line of sight strikes at right angles to the front and back surfaces of the lens. This prevents inducing unwanted sphere and cylinder power changes, which would otherwise be caused by tilting of the OC.

If the wearer's PD is less than the frame PD, then the frame front should be given face form by bending it at the bridge, allowing both cosmetic and optical alignment (Figure 5.2). A perfectly straight alignment of the frame front will tilt the OCs with reference to the line of sight and cause unwanted sphere and cylinder powers (Figure 5.3). (How these unwanted powers happen is explained in Chapter 18.)

In rare instances, the wearer's PD may be greater than the frame PD. If the wearer's PD *is* greater than the A + DBL of the frame (the frame PD), then *theoretically* the frame bridge would be bent so that the curve of the frame front is opposite to the normal curve of the face. When this occurs, the frame front is said to have *negative face form*. Although a negative face form may result in optical alignment, the situation is usually the result of having chosen a frame that is too small. Negative face form in a frame is cosmetically unsatisfactory. It should *not* be used (Table 5.1). Do not adjust a frame to create negative face form, even if the wearer's PD is so large that the lenses must be decentered outward!

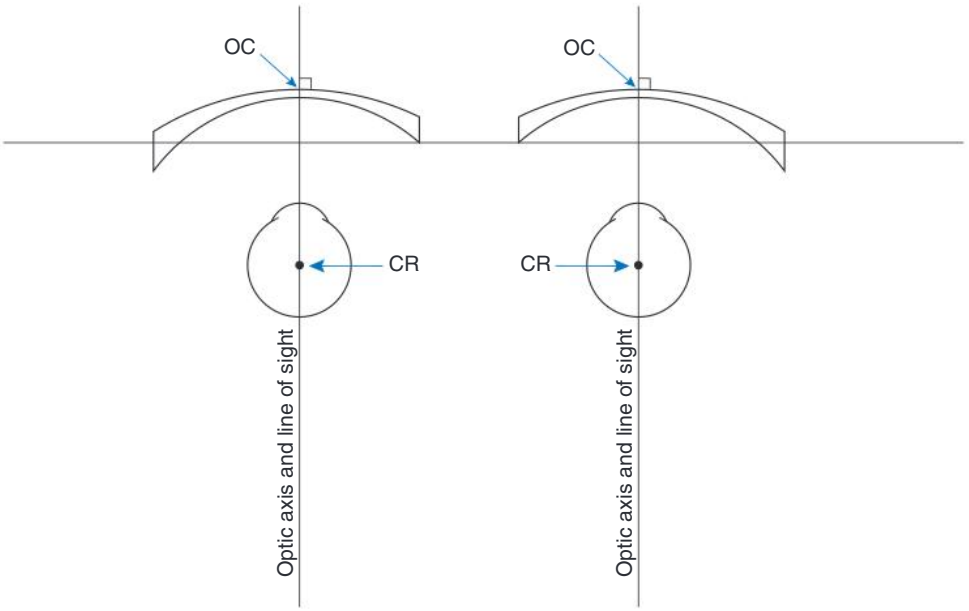


Figure 5.2 To prevent optical error caused by lens tilt, when the wearer's interpupillary distance (PD) is less than the frame's geometric center distance (frame PD), face form is required. This is because more of the lens blank has been removed nasally than temporally during edging. The reason for adding face form to a spectacle lens prescription is to keep the lens surfaces at the optical center (OC) perpendicular to the line of sight.

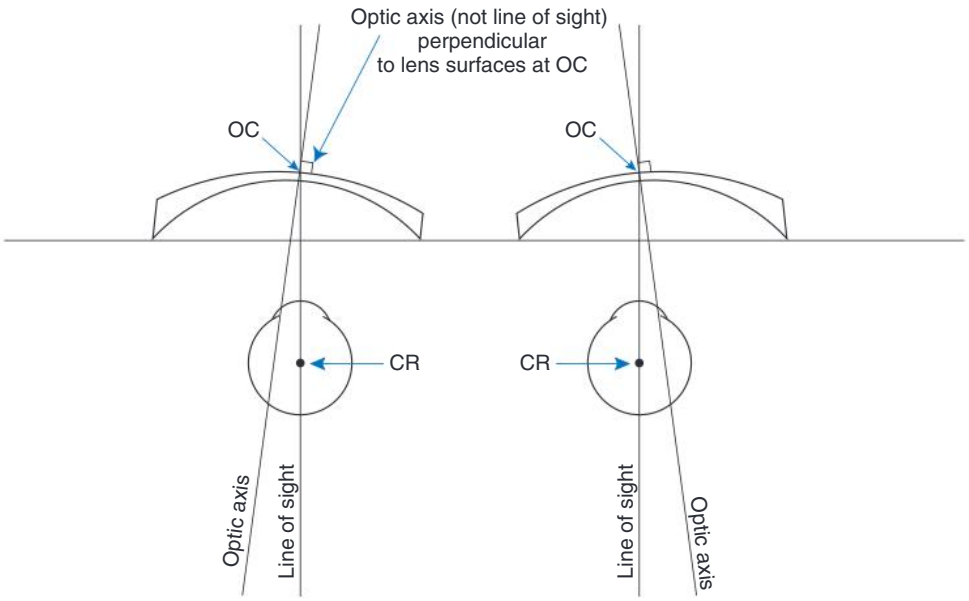


Figure 5.3 In this figure, the glasses have not been adjusted to include face form. Because the wearer's interpupillary distance is smaller than the geometric center distance, the line of sight crosses the lens optical centers (OCs) at an oblique angle. This results in lens tilt, inducing unwanted changes in the sphere and cylinder components of the prescription. CR stands for the center of rotation of the eye. The optic axis of the lens should pass through the center of rotation of the eye.

TABLE 5.1 Amount of Face Form Indicated

If	Then
1. PD = Eye size + bridge size	No face form
2. PD < Eye size + bridge size	Positive face form
3. PD > Eye size + bridge size	Negative face form (this is impractical and should not be carried out)

PD, Interpupillary distance.

Vertical Displacement

Unless otherwise specified, an optical laboratory will make a single-vision lens so that the MRP is centered vertically—halfway between the top and bottom of the frame's lens shape. Low-powered lenses made from traditional materials seldom require an MRP height to be specified. Optical problems caused by a vertical MRP placement that might need to be above the vertical frame center are so minimal with low-powered lenses that few wearers are bothered. However, this is not the case when lens powers increase, when different lens materials are used, or when aspheric lens designs are employed. In these instances, vertical MRP placement becomes important. For this reason, some offices routinely specify an MRP height to avoid confusion as to when it may or may not be necessary.

Optically Correct OC Placement

Consider a lens placed before an eye with the OC of the lens directly in the eye's line of sight (Figure 5.4). As light passes through the OC of the lens, it enters and leaves the lens at right angles to both front and back surfaces. The optic axis of the lens and the line of sight of the eye fall in the same place.

Note, however, that a lens with its OC directly in front of the eye should not be tilted. Figure 5.5 shows this incorrectly tilted lens. Tilting the lens when the OC is directly in front of the eye will both induce an unwanted cylinder component and alter the sphere value of the lens. (An optical explanation of this is found in Chapter 18.)

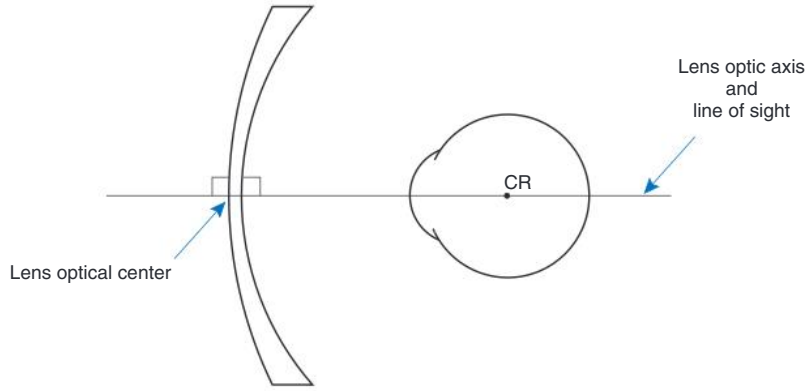
With most frames, the eye is slightly higher than the center of the lens. This is shown in Figure 5.6. The alignment shown in Figure 5.6 is not an optically correct alignment, since the optic axis of the lens does not pass through the center of rotation of the eye. Even though the lens is not tilted, light passing through the center of rotation of the eye also passes through the lens at an angle to both lens surfaces.

Fortunately, lenses are usually worn with the lower lens edge tilted toward the face. This *pantoscopic tilt* is the amount the frame front is tilted with reference to the plane of the face. To avoid the lens aberrations that would otherwise be caused by lens tilt, light following the line of sight through the center rotation of the eye must still pass through the lens OC at right angles. This can be accomplished by lowering the OC of the lens 1 mm for every 2 degrees of pantoscopic lens tilt and is shown in Figure 5.7. (Table 5.2 summarizes the relationship between pantoscopic tilt and OC placement.)

As a general rule, eyeglasses need to be adjusted so that the lower rims of the frame are closer to the face. This widens the viewing area for the wearer and is more cosmetically appealing. The correct fitting procedure is to first adjust the empty frame for pantoscopic tilt. This angle of tilt, in degrees, is noted. Next the pupil center height is measured. Afterward, according to a *2-for-1 rule of thumb*, 1 mm is subtracted from the height of the OC for every 2 degrees of pantoscopic tilt. However, the OC should not be dropped below the level of the horizontal midline of the frame.

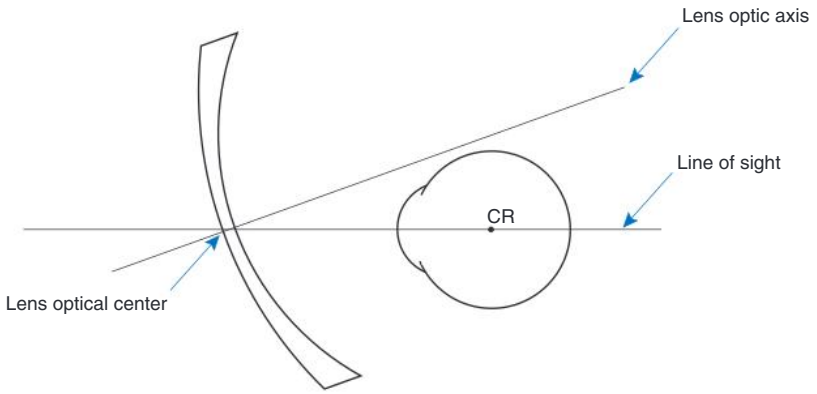
Summarizing How to Determine MRP Height

MRP height is determined by first measuring pupil center height. Pupil center height is measured with the dispenser's eyes positioned at the same level as the subject's eyes. The subject looks at the bridge of the dispenser's nose. Using a lens-marking pen, the dispenser draws a horizontal line on the glazed lenses through the pupil center for both right and left eyes (Figure 5.8). If there are no glazed lenses in the frame,



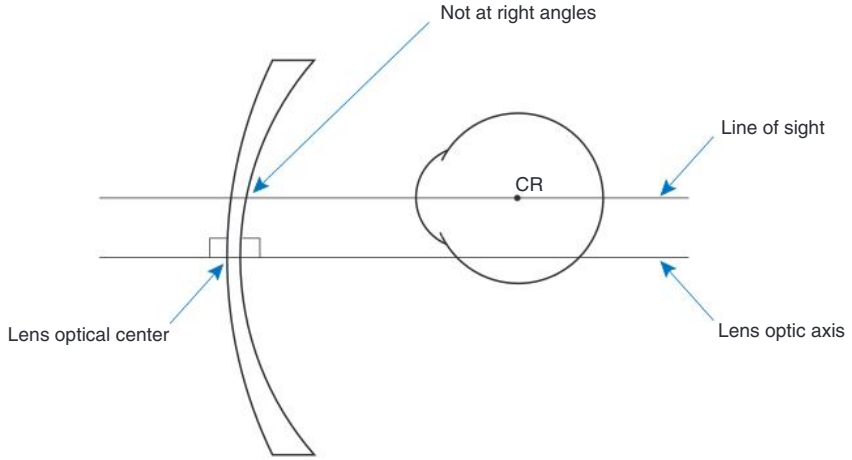
CORRECT

Figure 5.4 A properly adjusted lens allows the line of sight to pass through the optical center of the lens at right angles to the front and back surfaces. If the eye is midway between the top and bottom of the lens, and the optical center is directly in front of the eye, a proper optical adjustment contains no pantoscopic tilt. (Note: The glasses may look cosmetically better if the frame has some pantoscopic tilt anyway.) If the lens powers are low, there will be negligible negative optical results, and some pantoscopic tilt is acceptable.



INCORRECT

Figure 5.5 When the optical center is measured for center-pupil height, if the glasses have any pantoscopic tilt, the optic axis of the lens will not pass through the center of rotation of the eye.



INCORRECT

Figure 5.6 When the eye is above the horizontal midline of the lens without pantoscopic tilt, the optic axis of the lens will not pass through the center of rotation of the eye. This means that the wearer will experience lens aberrations corresponding to the effect of altering lens sphere and cylinder values.

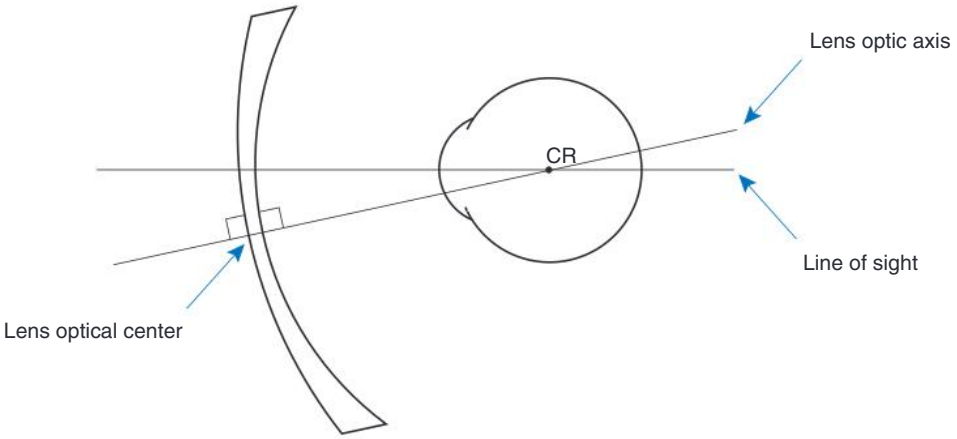


Figure 5.7 A correctly fit pair of glasses will drop the optical center 1 mm for every 2 degrees of pantoscopic tilt. This is also a good fitting situation because the average viewing area is not centered on a point on the lens directly in front of the eye. "The average patient moves his eye through a field of view, which is centered in a slight downward position, since we seldom have occasion to look as far above the horizontal as we do below. Even for viewing tasks other than through the bifocal segment, we look down at the sidewalk, down at store counters, even somewhat downward to drive a car to look at the road directly in front of us."[1]

transparent tape may be used. (The use of transparent tape is described in the section on measuring bifocal heights found later in this chapter.) Next, compensate for pantoscopic tilt using the 2-for-1 rule of thumb as described above.

Example 5.1

A metal frame with adjustable pads and a 40- mm B dimension is selected. The frame and pads are adjusted so that the frame sits on the nose and face as it should after dispensing. The frame front is tilted to the correct pantoscopic angle and, when viewed from the front, is observed to be straight on the face. Neither lens is higher than the other. The frame front has a 10-degree pantoscopic angle. Measure the MRP height, and modify this amount to compensate for the pantoscopic tilt.

Solution

In measuring the pupil center height, the distance from the lowest point on the inside bevel of the lower frame eyewire up to the pupil center is measured and found to be 28 mm. If the pantoscopic tilt is 10 degrees, then the height must be lowered by 1 mm for every 2 degrees of pantoscopic tilt, which in this case is 10/2, or 5 mm. The new MRP height is 28 − 5, or 23 mm. (If unspecified, the lab will normally place the MRP height on the horizontal midline at a height B/2, which would be 40/2 = 20 mm.)

Simultaneously Compensating for Pantoscopic Angle While Determining MRP Height

There is a simple method that makes it possible to compensate for pantoscopic tilt while determining MRP height. The dispenser is positioned at the same level as the subject. With the frame fully adjusted for height, pantoscopic tilt, and straightness, the subject is instructed to look at the bridge of the dispenser's nose. Next, the dispenser places a finger under the subject's chin and tilts the subject's head back until the frame front is perpendicular to the floor (Figure 5.9). With the subject's head in this position, a horizontal line is drawn on the glazed lens at the level of the pupil center. The distance from the lowest portion of the inside bevel of the lower eyewire to the horizontal mark on the lens is the MRP height. This height has already been corrected for pantoscopic tilt and does not require any compensation. (This is summarized in Box 5.1.)

MRP Placement for Polycarbonate and Other High-Index Materials

It is especially important to measure PDs monocularly and to consider the vertical position of the MRP when using polycarbonate and high-index materials. Many of these materials have more chromatic aberration than crown glass and regular (CR-39) plastic. (Chromatic aberration causes objects with high contrast border areas to have rainbowlike color fringes. Chromatic aberration may be visible with high-powered prescriptions made from lens materials with low Abbé values.)

Fitting eyewear correctly will help keep many types of aberrations under control. (For more on lens aberrations, see Chapter 18.) If other aberrations are minimized by good fitting techniques, a small amount of chromatic aberration is less likely to push overall aberration problems into the troublesome area. It should also be noted that the farther from the OC the eye looks, the more evident chromatic aberration may become.

MRP Placement for Aspheric Lenses

An aspheric lens typically has a central zone of constant lens surface power, with the power gradually changing toward the periphery of the lens. This means that the central zone must be well positioned both horizontally and vertically. Monocular PD and MRP height measurements are important to obtain.

TABLE 5.2 Amount of Pantoscopic Tilt Indicated

If	Then
1. Eyes at OC	No pantoscopic tilt
2. Eyes above OC	Pantoscopic tilt required
3. Eyes below OC	Retroscopic tilt is *theoretically* indicated (A need for retroscopic tilt may be an indication of an error in frame selection. No matter the reason, adjusting a frame so that it has retroscopic tilt is impractical and should not be carried out.)

OC, Optical center.

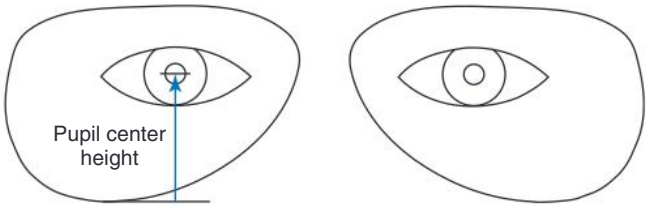


Figure 5.8 To measure pupil center height, mark the location of the pupil on the glazed lens with a short horizontal line or a cross. Pupil center height is the distance from the lowest level of the inside bevel of the lower eyewire up to the pupil center.

Figure 5.9 If the chin is raised until the frame front is perpendicular to the floor, major reference point height can be measured without compensating for pantoscopic tilt.

BOX 5.1 Steps in Measuring MRP Height

1. Frames are adjusted to fit the wearer, giving attention to nose pads, frame height, pantoscopic tilt, and straightness of the frame on the face.
2. Fitter positions himself or herself on the same level as the wearer.
3. Wearer fixates on the bridge of the fitter's nose.
4. Fitter tilts wearer's chin back until frame front is perpendicular to the floor.
5. Fitter marks the location of the pupil centers with short horizontal lines on the glazed lens.
6. Fitter measures MRP height as the distance from lowest portion of the inside bevel of the lower eyewire to the line on the glazed lens.

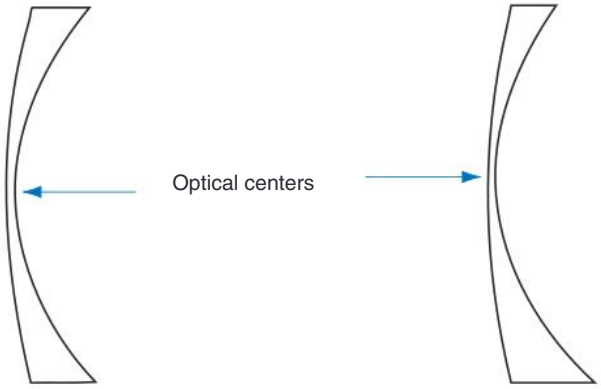


Figure 5.10 Moving the optical center of a high minus lens too far upward will cause the lower edge of the lens to be too thick.

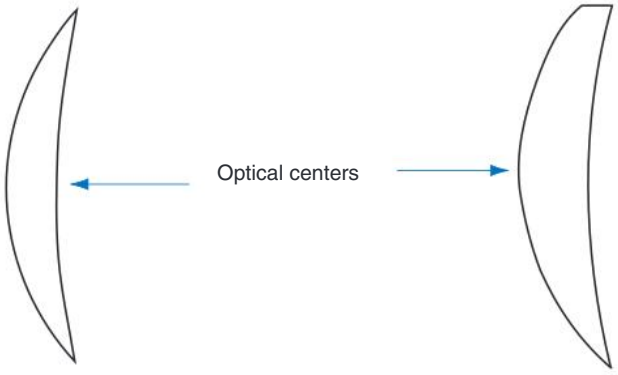


Figure 5.11 These two high plus lenses have the same refractive power. The lens on the left has the optical center halfway between the top and the bottom. The lens on the right has the optical center too high for a lens of this power. As a result, the upper edge is excessively thick.

Other Ways of Positioning MRP Height

Some dispensers measure pupil height and do not lower the MRP from this position to compensate for pantoscopic tilt. Although this may help prevent chromatic aberration with distance viewing for polycarbonate and high-index lenses, it can cause aberrations because of lens tilt and result in a thicker lens. Raising the OC of a minus lens makes the top thinner and the bottom thicker (Figure 5.10). Raising the OC of a plus lens makes the top thicker and sometimes increases center thickness (Figure 5.11). Therefore, before ordering a high-powered lens with a high OC, it is advisable to consider the resulting edge thickness.

If the dispenser fails to specify an MRP height, the laboratory will center the lens vertically in the frame. For most low-powered crown glass and CR-39 plastic lenses, no problems will be encountered. For polycarbonate, aspheric, and high-index lenses, the MRP height should be measured.

Notes

1. It is not advisable to move an MRP height below the horizontal midline (datum line) of the glasses unless the lenses are intended exclusively for near work.
2. When the pantoscopic angle is especially large, it may be advisable to (a) reconsider the frame selected and choose one that will place the eyes higher in the frame, (b) reduce the pantoscopic tilt, or (c) just not lower the MRP by the full 2-for-1 amount.

Vertex Distance

Vertex distance is the distance from the back surface of the spectacle lens to the apex of the cornea. During the exam, a 13.5-mm vertex refracting distance is considered average. However, the best fit for spectacles is usually obtained by fitting the frame as close to the eyes as possible without having the lashes rub the lenses.

The depth of the spectacle lens base curve affects the final vertex distance. Each increase of 1 D of base curve increases the depth of the vertex distance by approximately 0.6 mm. The exact amount of vertex distance increase will depend on the size of the lens. Vertex distance is important when fitting someone with long lashes. Be sure to observe the person from the side with the sample frame. Have the person blink to note the lash clearance. Vertex distance becomes more of a concern in higher powered prescriptions because a change in vertex distance induces a change in both the spherical and cylindrical powers of the lenses.

Measuring Vertex Distance

The classical instrument used to measure vertex distance is the *distometer* (Figure 5.12). The following technique is used to measure vertex distance: With the spectacles in place, the subject is instructed to close the eyes. The flat side of the "scissors" end of the distometer is placed against the closed lid. When the end of the distometer is pressed, the other side of the "scissors" moves out to touch the back surface of the spectacle lens. When the two parts of the distometer touch the lid and lens simultaneously, vertex distance is read from the instrument. The instrument takes average lid thickness into consideration so that the reading does not have to be compensated (Figure 5.13).

Today, a distometer is seldom used in the optical dispensary. Instead, if a vertex distance measure is desired or required, a tablet-based measuring system that includes the ability to measure vertex distance is used. This is described in Chapter 3, *Measuring the Interpupillary Distance.*

For more on how prescription powers change with changing vertex distances, see Chapter 14.

MEASURING FOR MULTIFOCAL HEIGHTS

The methods used for segmented multifocal lenses and those used for progressive addition lenses are very similar. The eye reference points are not the same. Progressive lenses use the center of the pupil for reference. Chapter 20 deals specifically with progressive addition lenses. We will start with the basics of how to measure for progressive addition lenses in this section. But for understanding various designs of progressive addition lenses and how they work, see the section titled *Measuring for and Ordering the Progressive* in Chapter 20.

Measuring for Progressive Addition Lenses

The reference point for a progressive addition lens is called the *fitting cross.* The fitting cross is to be placed directly in front of the wearer's pupil. Two measurements are needed, and both have already been discussed earlier in this chapter.

Figure 5.12 A distometer is the classical instrument for measuring the distance from the back surface of the lens to the front surface of the eye.

Figure 5.13 The distometer is positioned so that the stationary part of the instrument is against the closed lid. When the probe touches the back surface of the spectacle lenses, the vertex distance may be read from the scale. Vertex distance may also be measured by newer tablet-based measuring systems.

The first is the monocular PD. Measure the monocular PDs for right and left eyes as previously described, and record them.

The second measure is the *fitting cross height.* (It should be noted that instead of saying "fitting cross height," many commonly refer to this height as the "seg height" as if it were a bifocal, even though a progressive lens does not have a segment. Even many laboratory order forms ask for seg height for a progressive addition lens instead of fitting cross height.)

Progressive lens fitting cross height is measured in basically the same way as MRP height for regular single-vision lenses is measured. The only difference is that no vertical compensation is made for pantoscopic tilt. With the selected frame properly adjusted, as it will be when worn, the dispenser positions himself or herself at the same eye level as the wearer. Short horizontal lines are drawn on each lens through the centers of the pupils. Remove the eyeglass frame and measure the distances from the lowest level of the inside bevel of the lower eyewire up to the level of the line for both right and left lenses independently. This was shown earlier in Figure 5.8. This measure can be done with a PD ruler but may be more easily accomplished by using a centration chart such as the one shown in Figure 20.2. The specifics on how this is done is explained in Chapter 20.

The accuracy of these measurements is very important. If they are not exact, the area of increasing lens power needed for viewing intermediate and near objects will not be located where it needs to be and will lead to dissatisfaction.

Measuring for Bifocal Lenses

The actual techniques for measuring bifocal height are not any more difficult than measuring the PD. There are, however, a few more considerations that must be taken into account to prevent certain difficulties.

Measurement for segment height should be done using only the actual frame that will be worn or one of exactly the same size and type. Any variations in size must be precisely compensated for, as explained in this chapter in the section on *Compensating for an Incorrectly Sized Sample Frame.* The frame must be carefully positioned to sit at the same height at which it will be worn.

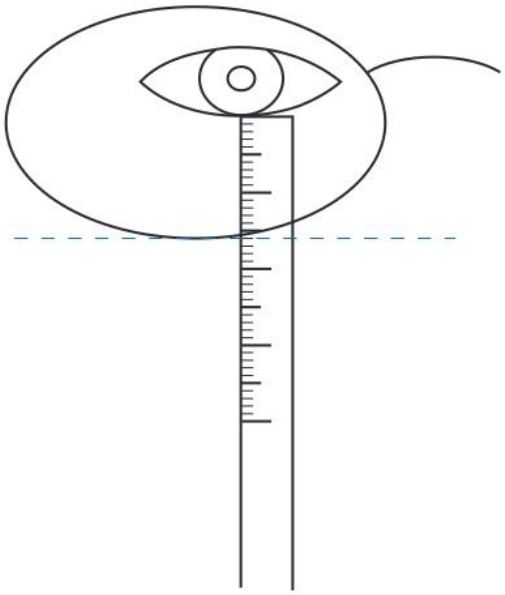


Figure 5.14 Measuring for bifocal height. When using the inside edge of the lower eyewire as reference, an additional amount must be allowed for the depth for the lens bevel in the groove. Although this may vary somewhat, an additional 0.5 mm added to the measure is normally suitable. Alternately, it may be easier to estimate the depth of the groove and measure directly to this estimated location.

Lower Limbus Method

The dispenser positions himself or herself on the same level as the wearer and directly in front of the wearer. The wearer is instructed to fixate on a point straight ahead at eye level—most often, the bridge of the dispenser's nose.

When using the PD ruler to measure bifocal height, hold it vertically with the scale extending downward, and align the zero point with the lower limbus (Figure 5.14). The bifocal height is indicated by the figure on the scale of the ruler that corresponds to the level of the lowest part of the groove inside the lower eyewire (Box 5.2).

The lowest portion of the eyewire must be used, even if it is not precisely under the limbus. Certain frames have a lower eyewire that slants, a problem best illustrated by the aviator frame shape. The distance from the top of the seg to the eyewire immediately below it is notably different from the distance to the lowest part of the eyewire (Figure 5.15).

BOX 5.2 Steps in Measuring Bifocal Height Using the Lower Lid or Limbal Method

1. Fitter positions himself or herself on the same level as the wearer.
2. The wearer fixates on the bridge of the fitter's nose.
3. Holding the frame in correct wearing position, the fitter places the PD ruler vertically in front of the wearer's right eye. The zero point is at the lower limbus, and the ruler scale is positioned downward.
4. For a rimmed frame, the fitter reads the scale at the level of the lowest point where the inside of the groove would be. For a rimless frame, the reference is the level of the lowest point on the demo lens.
5. Repeat for the left eye.

Note: There is an alternative method for measuring bifocal height that does not require a ruler to be held in front of the wearer's face. Instead, as shown in Figure 5.16, the glazed lenses are marked at the level of the limbus with a marking pen, the fitter removes the frames from the wearer, and a ruler is used to measure the distance from the marks to the lowest part of the lens.

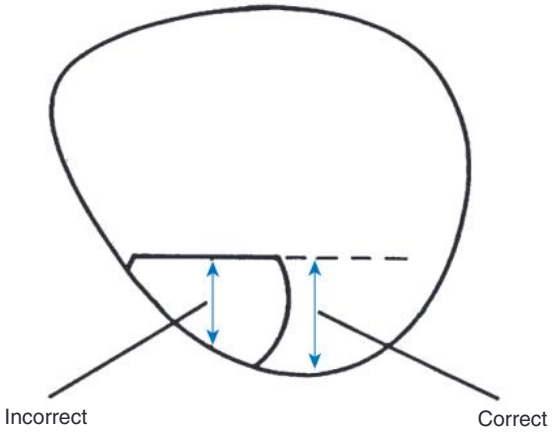


Figure 5.15 The lowest portion of the lens as positioned in the frame must be used in measuring seg height. This is true even if the height at the center of the seg has a different measurement. (Note: The segment height is *not* measured using the outside of the frame. The edge of the lens is the reference used.)

Lower Lid Margin Method

The lower lid margin is often used as a reference point for measuring bifocal height instead of the lower limbus. The difference is frequently academic because the two are usually in approximately the same position.

The lower lid margin position can vary considerably more than the lower limbus position, however, making the lower limbus a more consistent reference point.

Subjective Determination

Subjective determination is the most accurate means of determining the seg height and of assuring the wearer that the bifocal will be positioned properly. The proper bifocal position for each person, of course, is determined with the occupational and personal characteristics of the individual in mind.

Marking on the Glazed Lens. When the sample frame has glazed (demo) lenses, the level of the bifocal can be marked on each lens with a marking pen instead of measuring with the PD ruler. With the dispenser and wearer on the same level and the wearer looking straight ahead, a short horizontal mark is drawn at the proposed level of the bifocal segment line (Figure 5.16). This can be checked before ordering by lengthening the line to simulate the width of the bifocal (Figure 5.17). This way the wearer can be given the opportunity to evaluate the suitability of the proposed height. Ask the wearer to stand and evaluate the position of the line.

Figure 5.16 Using a marking pen, the proposed level of the bifocal line can be drawn on the glazed lens in the new frame. If the wearer will be using old frames, the mark is made on the old lenses.

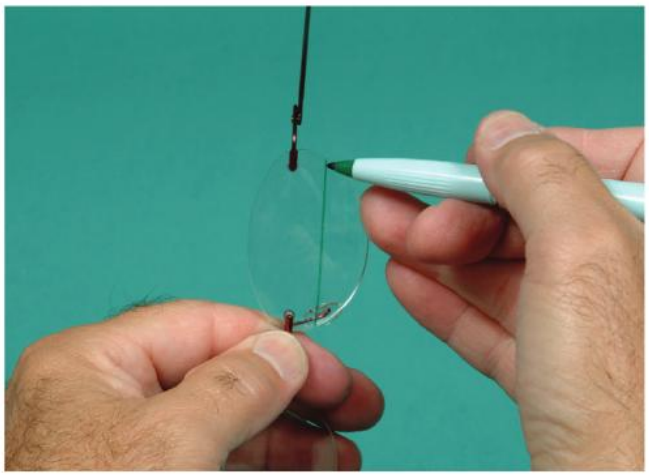


Figure 5.17 Drawing a complete line at the proposed bifocal height will allow the wearer a realistic evaluation of where the segment will be located after the finished lenses are in the frame.

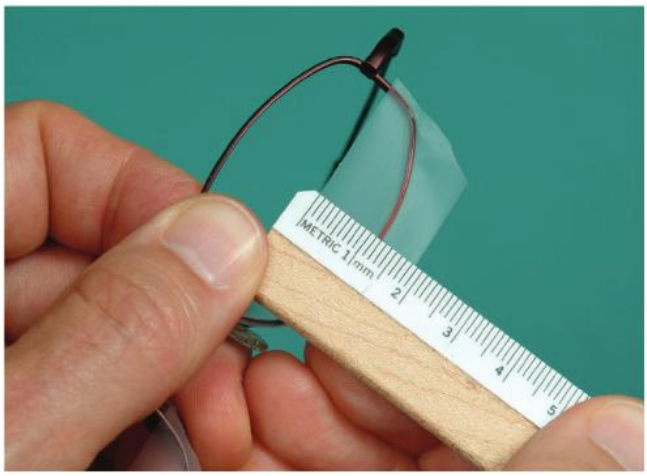


Figure 5.19 The simulated bifocal height is measured from the lowest part of the inside of the lower eyewire.

Give the wearer something to hold in the reading position. Encourage the wearer to simulate normal working conditions and evaluate whether the line is too high, too low, or just right. If the line is too high or too low, redraw the line and have the wearer re-evaluate the new height. When the level is judged as satisfactory, measure the distance from the lowest level of the inside bevel of the lower eyewire up to the drawn bifocal line for each lens.

Using Transparent Tape. The method using transparent tape is slightly more time consuming but is useful for checking when there are no lenses in the frame. This method also works for checking unequal seg heights. A strip of tape is placed across the lower portion of the empty frame at exactly the level of the proposed segment (Figure 5.18). The proper height is checked in the same way as a regular bifocal (Figure 5.19), and the tape is readjusted if necessary. When the wearer looks into the distance, the taped area should not interfere with vision. When looking up close, the nearpoint material should be seen as if located within the area covered by the tape (Figure 5.20).

Figure 5.20 Subjectively checking seg height. The wearer should be readily able to locate reading or near point material within the transparent tape area. The same is true when using a frame with glazed lenses that have been marked for height with a lens marking pen.

Using Fresnel Press-On Segments

By using Fresnel optics, it is possible to produce a uniformly thin, flexible, stick-on lens or prism. Such lenses are normally used to provide high amounts of prism in vision therapy or to apply prism in certain sections of a lens. However, *Fresnel lenses* are also available as temporary flat-top bifocal segments. By obtaining a series of *Fresnel press-on segments* in increasing powers, it is possible to stick the lenses on the wearer's old single-vision lenses or on the glazed lenses in the new frame (Figure 5.21). Having the wearer's prescribed near power in the removable segment will add a dimension of reality that will enable the wearer to judge more accurately the most useful bifocal height for a given work situation. (For more on Fresnel prisms and lenses, see Chapter 17.)

Measuring for Trifocals

The techniques for measuring trifocals are identical to those for measuring bifocals, except the reference is the top of the trifocal

Figure 5.18 To simulate the level of a bifocal segment, a strip of transparent tape is placed across the lower half of each eyewire.

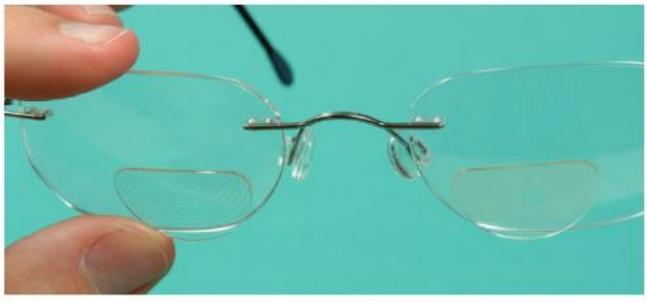


Figure 5.21 Fresnel press-on segments are removable and reusable. They offer a greater degree of reality when asking the wearer to subjectively judge the most appropriate segment height.

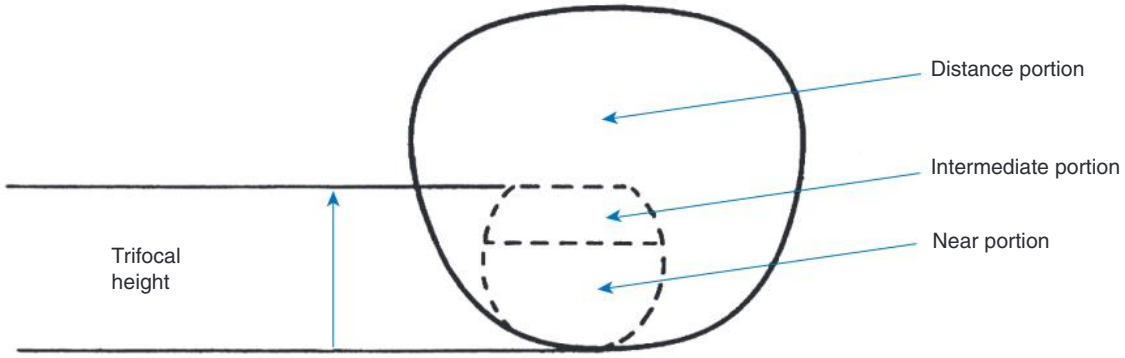


Figure 5.22 No specification for lower seg line is necessary when ordering trifocal lenses. The style of trifocal lenses ordered dictates this position. The top of the intermediate portion is the position measured.

intermediate segment rather than the top of the lower near segment. The trifocal height is the top line (Figure 5.22).

Bifocals enable the wearer to see at two distances clearly: (1) off in the distance through the upper portion of the lens and (2) at reading distance for the smaller segment area in the lower portion of the lens. When it becomes necessary to see clearly at an intermediate distance (usually an extended arm's length), trifocals are used. Trifocals differ from bifocals only through the addition of an intermediate portion immediately above the near portion, giving the wearer three distances of clear vision instead of two.

Lower Edge of Pupil Method

The lower edge of the pupil method is similar to the lower limbus and lower lid margin methods used for bifocals. For trifocals, however, the lower pupil margin is aligned with the zero mark of the vertically held PD ruler. The reading is that point where the scale intersects the level of the inside groove of the lower eyewire (Figure 5.23). Then 1 mm is subtracted to compensate for pupil clearance while viewing objects in the distance. Thus, if the seg height for a trifocal measures 18 mm from the edge of the pupil, the net seg height ordered would be 17 mm.

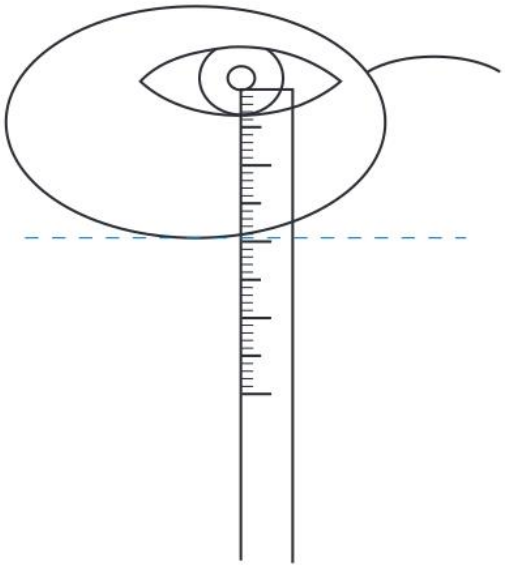


Figure 5.23 Measuring for trifocal height starts as shown. Subtract a full millimeter so that the intermediate seg does not get in the way for distance viewing. If the frame has a groove for the bevel, that must also be considered.

Subjective Determination

The subjective technique is again similar to that used for bifocals, with the addition of a test for the third section of the lenses. When a marking pen and glazed lens are used, the two trifocal lines may be drawn on the lens. The area in between is "colored in" with the pen. Objects viewed through this colored intermediate area will appear tinted.

If the total seg height is lowered, the near portion area will be reduced and vice versa. For example, assume that a trifocal with a 7-mm intermediate portion is to be fitted 17 mm high in the eyewire. This leaves 10 mm for the near portion of the seg (17 total − 7 intermediate = 10 near). If the top of this intermediate seg is too high, lowering it reduces the reading portion. If the reading portion is increased, the top of the trifocal is raised.

The feasibility of using a trifocal in a given frame can thereby be easily ascertained. If the trifocal seg is deliberately set very low, the resulting small near (reading) portion will probably permit a too little reading area; but, on the other hand, increasing the reading area may place the trifocal intermediate portion high enough to interfere with distance vision. When no suitable trifocal position in the selected frame is possible, a frame with a greater vertical depth is indicated.

Comparison With Old Lenses

When a person who is currently wearing bifocals is refitted with new bifocals, the segment position may be either maintained or changed. If a person is dissatisfied, the complaint will indicate the necessary change in position. If the bifocals were "always in the way," the seg height was too high. If the seg height was too low, the wearer will complain of stiffness of neck caused by constant head tilting.

Any change that is made, however, should be done using the same techniques described for new multifocal wearers to ensure correct positioning. This is also true for a bifocal wearer changing to trifocals. If the trifocal is merely added to the bifocal height, the tops may intrude into the pupillary area.

Seg Height Factors

If a person is satisfied with the seg height currently worn but is changing any aspect of the frame, the specifications necessary to achieve the previous seg height may be different. Only with exactly the same frame shape and size will the seg height measurements be identical to the previous order.

One factor that influences the position of the seg is the bridge. The shape and size of the bridge determine the height at which the frame sits on the nose. For example, two frames might both have a vertical dimension of 38, but the bridge on one frame might hold the eyewire higher on the face than a differently shaped bridge on the other frame.

The influence of lens size on segment height is evident in the vertical depth if one frame is a 38-mm eye size and the other is a 42-mm eye size. Even if the bridges hold both frames in relatively the same position, as the horizontal size increases, so does the vertical size.

Lens shape influences segment height. The seg height might be 15 mm for a narrow frame and 20 mm for a deep frame, yet both frames could place the segment line right at the lower limbus.

When measuring to match the segment height of a new bifocal lens with that of an old bifocal lens, have the person wear his or her old glasses. Note the location of the segment line on the face or in relation to the lower lid. Measure from the lower lid to the seg line: plus if above the lower lid, minus if below it (Figure 5.24, *A*). Place the new frames on the face. Measure the distance from the lower eyewire to the lower lid, then add or subtract the distance from the lower lid to the old seg line (see Figure 5.24, *B*).

Measuring for Double Segs

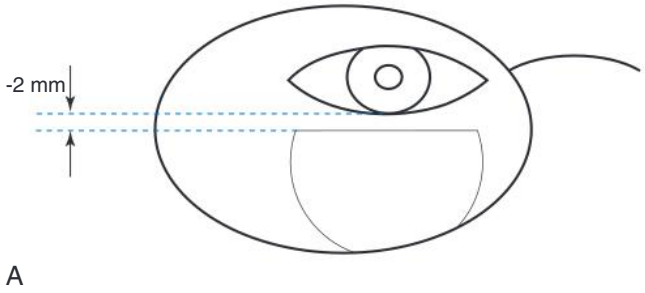
A double seg lens has near segments in both the lower portion and the upper portion of the lens (Figure 5.25). This upper seg allows the wearer to do near work more comfortably when the working area is above eye level. Double segs are available in several seg shapes.

Measuring for a double seg is done in practically the same manner as for the normal bifocal. The only initial consideration is the lower seg height. This can be measured by any of the methods described previously.

When a double seg lens is ordered, the lower edge of the top segment will automatically be 13 to 14 mm above the lower seg line position. With the frame in place, note the position in the frame where the upper seg will begin. If there will not be a large enough field of view in the upper seg, either a different frame with more area above eye level must be chosen or the lower seg must be placed deeper in the frame to bring down the upper seg. A reasonable minimum area for the upper seg is considered to be 9 mm.[2]

The opposite problem can result if the subject has previously worn the bifocal seg lower than normal. The upper seg will be so low that it will partially obscure distance vision. The lower seg then has to be raised until the upper seg is high enough that it is no longer disturbing the wearer.

(For a summary of basic starting points used in placing segment and progressive addition fitting heights, see Box 5.3.)



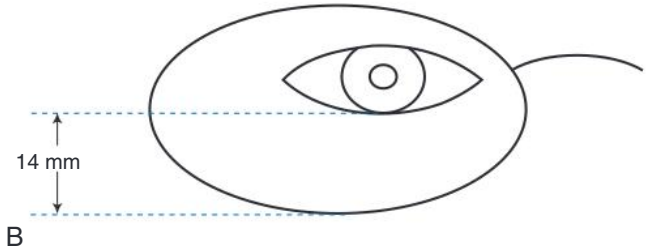


Figure 5.24 Duplicating the old seg height positions for use in the new frame or for a second pair of glasses is done by first measuring from the lower lid, down (or up) to the seg line. The measure will be plus if the old seg line is above the lower lid and minus if it is below it. In the figure, this measurement is −2 mm. Next, with the new frame in place, the distance from the lower lens edge up to the lower lid is measured. In the figure, this measurement is 14 mm. The distance in **(A)** is then added to the distance in **(B)** to determine the seg height for the new or second pair of glasses so that both old and new segment heights match. For the example, this is −2 mm + 14 mm = 12 mm.

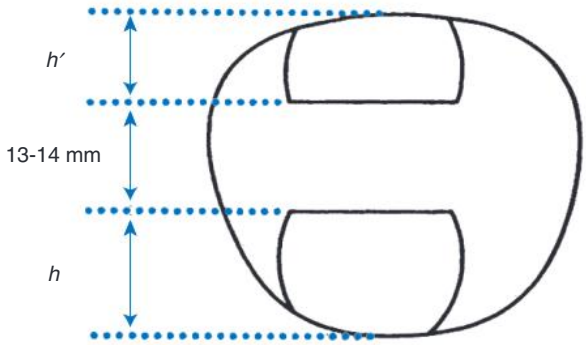


Figure 5.25 The double seg lens. Most double seg lenses have a 13- to 14- mm distance between segs. Measure *h′* is therefore dependent upon both seg height *h* and the vertical dimension of the frame chosen.

Unequal Seg Heights

Both eyes should be measured independently for bifocal or trifocal heights (Figure 5.26). If one eye is higher than the other and the segments are placed at equal heights, the wearer will have a blur area considerably larger than normal; one eye sees the segment line first as the person looks down, then, as that eye begins to clear, the other eye sees the line and begins to clear later.

Before prescribing unequal segment heights, be sure to check (using the actual frame to be worn) to be certain that the frame sits straight on the face. A crooked frame obviously will result in unequal segment heights.

BOX 5.3 Starting Points: Bifocal, Trifocal, and Progressive Height Placement

Flat-top bifocal segment height	Seg top at the lower lid, or set the lower limbus
Trifocal segment height	Top of segment intermediate 1 mm below the lower edge of the pupil
Occupational double segment heights	Lower seg top placed at the lower lid or limbus The upper segment is fixed at 13 to 14 mm above the lower segment To work properly, the lower edge of the upper segment should be 9 mm or more below the top of the edged lens. If it will not be, either lower the lower segment height or choose a different frame
Progressive addition fitting cross height	Fitting crosses placed at the pupil centers

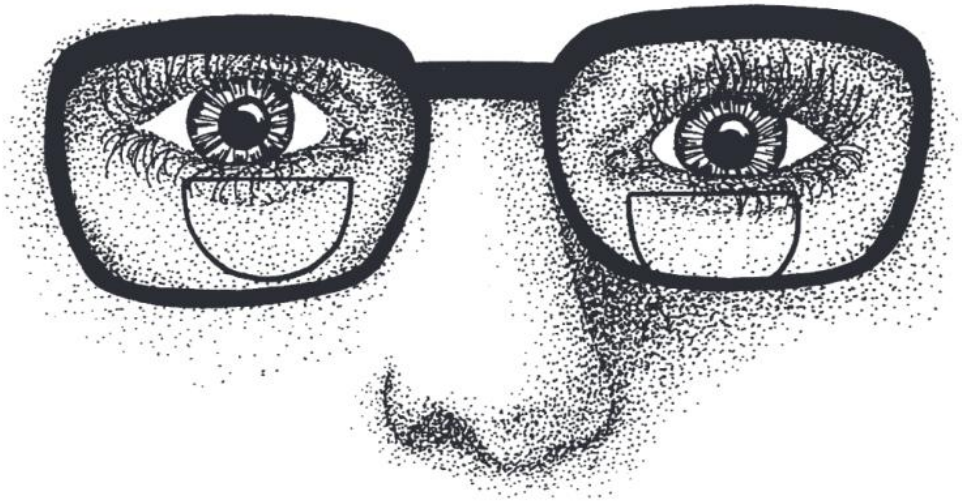


Figure 5.26 A difference in measured seg heights is sometimes required so the person's eyes will meet the bifocal line simultaneously on downward gaze.

When unequal segment heights are used, they should be called to the wearer's attention. Otherwise they will be discovered as an "error."

Transparent Tape or Drawn Line Methods Used Subjectively

To subjectively check the relationship of the two segment heights to one another, have the person look at a given near object and slowly tilt his or her head back until the "line," or top of the tape, first hits the object. Next, alternately occlude the wearer's eyes to determine whether the "line" is at the same point for each eye. If not, move the tape until there is an equalization. Then measure the height of the tape or drawn line from the lower eyewire for each lens (Box 5.4).

Transparent Tape or Drawn Line Methods Used Objectively

To check the segment height relationship objectively using the transparent tape or drawn line methods, have the wearer look at the bridge of the dispenser's nose as the dispenser tilts the wearer's head back slowly and notes which "segment" reaches the lower pupil edge first. The tape level is readjusted until both "lines" reach the pupils at the same time (Box 5.5).

Segment Height and Vertical Prism

A prism causes the light to deviate from its path to a new direction. A ray of light will be bent toward the base of the prism, causing the image of the object viewed to be displaced in the direction of the apex. This also causes the eye to turn in the direction of the perceived object.

A prism may be necessary in a prescription if there is a slight paralysis of one or more extraocular eye muscles. Without the help of the prism, the person may experience diplopia, or double vision. Even if a person does not have double vision, a prism may be prescribed for ocular comfort. If a tendency for the eyes to turn is present, the person is said to have a phoria condition (i.e., a tendency of the eyes to turn, but with no actual turning manifested) and must exert constant effort to keep both eyes pointing straight ahead. This can lead to fatigue and headaches. A prism can be used to relieve this discomfort. If one eye tends to turn down or up, a vertical prism with the base of the prism up or down is prescribed. If the eyes turn in or out, a horizontal prism with the base of the prism out or in may be prescribed.

When a vertical prism is prescribed, one eye is allowed to turn up slightly more than the other (Figure 5.27). Given equal seg heights, when a person with prescribed vertical prism in the prescription is wearing bifocals or trifocals and looks down toward an object in the near field of view, there is a point where one eye crosses the bifocal line before the other. This inequality is not detected in measuring for seg heights if the condition prescribed for is only a phoria.

The inequality of turn can be calculated, however, using the definition of a prism diopter: 1 cm displacement of the image of an object at a distance of 1 m. Assuming a 30- mm distance from the back surface of the spectacle lens to the center of rotation of the eye, the difference in the vertical position of the two eyes at the spectacle plane can be calculated. This is the difference in seg height from that which was measured.

BOX 5.4 Steps in Subjectively Checking Equality of Seg Heights

1. On the demo lens of the sample frame, draw a bifocal line on each lens with a marking pen or use tape on the lenses instead.
2. The wearer is positioned in a normal reading position. (Check to be sure the glasses are straight on the face.)
3. The wearer starts by looking at a specific line on a reading card while looking through the *distance* portion of the lens.
4. Then the wearer slowly tilts the head back until the reading line starts to be blurred by the drawn line or tape on the lens.
5. The fitter then alternately covers one of the wearer's eyes first and then the other to see if the same reading line blurs for both eyes.
6. If not, the line or tape on one of the lenses is adjusted.
7. Repeat until equal.

BOX 5.5 Steps in Objectively Checking Seg Height Equality

1. Fitter should be positioned at wearer's eye level.
2. Wearer fixates on bridge of fitter's nose.
3. Fitter places finger under wearer's chin and slowly tilts wearer's head back.
4. Fitter observes seg lines to see which line reaches the pupil first.
5. Adjust the tape or drawn line level.
6. Repeat until even.

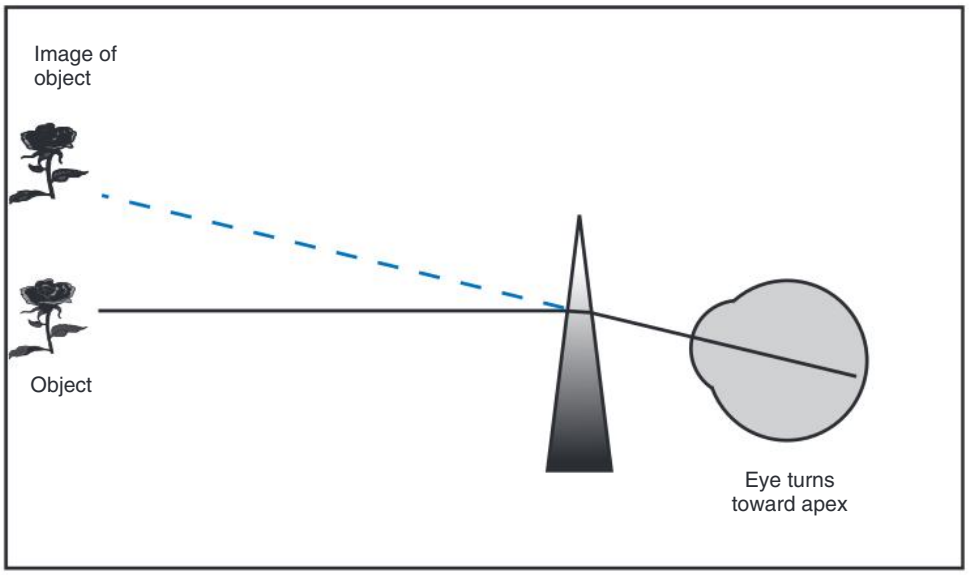


Figure 5.27 A vertical prism causes the eye to turn. This requires an alteration of seg height.

According to Figure 5.28, for one prism diopter, it can be seen from similar triangles that:

$$\frac{10}{1030} = \frac{x}{30}$$

and so

$$x = 0.29\,\text{mm}$$

or approximately a 0.3- mm difference for every diopter of vertical prism prescribed.[3] (In Europe, the average distance from the center of rotation of the eye to the lens is assumed to be less than 30 mm. Therefore, their compensation value is given as 0.25 mm for every diopter of vertical prism. Shorter vertex distances favor lower compensation values.)

Assuming a 0.3- mm compensation for every 1 D of prescribed vertical prism, compensations are summarized in Table 5.3.

The seg top is always displaced from its original location in the direction of the apex (pointed edge), opposite from the base direction of the prism. (The seg line moves in the direction the prism apex points.) For example, if a prescription included 3 Δ base-up prism before the right eye, then the right seg height should be *lowered* approximately 1 mm from its measured position.

TABLE 5.3 Segment Height Change Indicated in the Presence of Vertical Prism*

Prism Diopters	Total Segment Height Difference (mm)
1	0.3
2	0.6
3	0.9
4	1.2
5	1.5
6	1.8

*When vertical prism is present in a pair of glasses, segment height should be compensated. Each of the prism amounts listed on the left requires a compensated segment height difference as shown on the right.

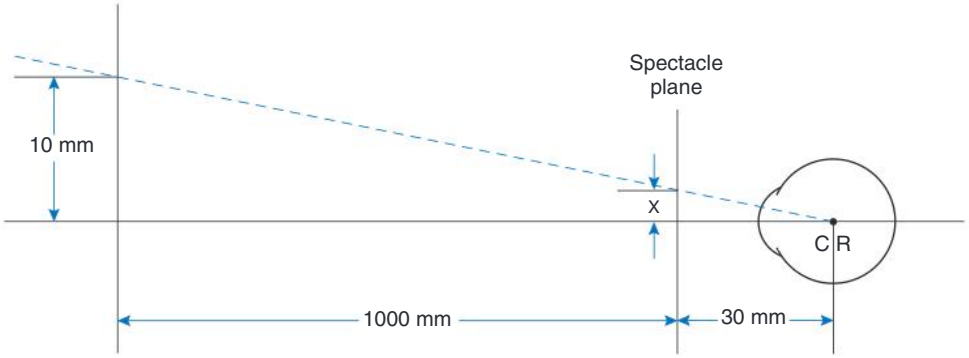


Figure 5.28 Diagram showing required difference in seg heights (*x*) when one prism diopter of base-down vertical prism is prescribed.

Example 5.2

A wearer selects a new frame. The dispenser uses the newly selected frame to measure seg height. Both right and left seg heights are measured as 21 mm. If the right lens has 3 Δ base-down prism, what segment heights should be ordered so that the pupils reach the segment lines at the same time once the prism is in place?

Solution

Because the right lens has base-down prism, the right eye will turn upward toward the apex of the prism. The amount the eye will turn equals 0.3 mm for each diopter of vertical prism. Therefore, the eye turns $0.3 \times 3 = 0.9$ mm, or 1 mm, when rounded. This means that the right segment height must be raised 1 mm. The final seg height should be ordered as:

R : 22 mm
L : 21 mm

Example 5.3

Suppose a wearer has a prescription that reads as follows:

R : −2.50 − 1.00 × 180 2.5 Δ base up
L : −2.50 − 1.00 × 180 4.5 Δ base down
+ 2.00 add

The selected frame is properly adjusted before seg height measurements are taken. Seg heights are measured using the empty frame. They are found to be:

R : 21mm
L : 21mm

How should the seg heights be adjusted to allow for the influence of the prescribed vertical prism once the lenses are in place?

Solution

To solve the problem, first decide which seg height will be raised and which will be lowered. Because the seg height will be displaced in the direction of the apex (i.e., opposite the base direction), the right seg height will be lowered and the left seg height raised.

To continue solving, next consider how far each seg height must be moved. Remember that each prism diopter yields 0.3 mm of movement. For the right eye, this is $2.5\ \Delta \times 0.3 = 0.75$ mm of movement. For the left eye, we find $4.5\ \Delta \times 0.3 = 1.35$ mm. Therefore, to the nearest millimeter the seg heights will be:

R : 20 mm
L : 22 mm

The same principles that are explained here for segment heights also apply to progressive addition lens fitting cross heights. For more information on how vertical and horizontal prism affects fitting cross heights and monocular PDs, see Chapter 20.

Variations of Seg Height

It is not reasonable to expect that every person is best served with a bifocal segment height that comes to the level of the lower limbus. It should be understood that the lower lid or limbal margin techniques described above are simply the default positions that work for most wearers. Consideration must be given to adjusting this default position in certain circumstances.

Posture

Perhaps the most obvious influence on segment height is posture. The person who "walks tall" or erect and carries the head back may find that the normally placed segment is constantly interfering with distance vision. This person would benefit from a segment placed at a level lower than usual because tilting the head back moves the segment higher and into the line of sight.

The person with the opposite tendency (i.e., that of carrying himself or herself in a somewhat stooped-over manner) could wear the segment slightly higher than usual.

These extremes in posture should be noted when apparent, although they are not the norm.

Height

A tall person sometimes needs segments set slightly lower than normal because the eyes must turn downward to a greater degree to sight the floor. The bifocal line would be more likely to interfere if placed at the normal level. Shorter persons, however, should not be given higher than normal seg heights.

Occupational Need

The person who wears bifocals and works at a desk all day may need a higher (and wider) segment than the person who works outdoors and who seldom is required to do any close work. However, a person who works at a desk is likely to be using a computer. Computer screens are generally farther from the eyes than print reading material. This means that an intermediate distance must be clear. Therefore, bifocals may not be the best alternative. For alternative computer and other appropriate occupational lens-viewing choices, see Chapter 19, *Segmented Multifocal Lenses*, and Chapter 20, *Progressive Addition Lenses*. In Chapter 20, see the section on *Speciality Progressive-Style Lenses*.

Round Segs

Bifocals with round segments need to be positioned about 1 mm higher than flat-top bifocals because their upper area is not wide enough to be as useful. The round bifocal is positioned only 1 mm higher because it would be difficult to raise it significantly more without interfering with distance vision.

For example, a round, 22- mm wide seg has its segment OC 11 mm from the top. The location of the segment OC is the widest part of a bifocal. If a seg were fitted at a 14- mm height, the center of the seg (and widest viewing area) would be only 3 mm above the frame's lower rim. If a flat-top seg were used at the same height in the same frame as the round seg (i.e., 14 mm high), the segment OCs (and the widest part of the bifocal segment) would be 9 mm above the lower rim of the frame. Because of this, it is understandable why round segment lenses are rarely used. Small, round bifocals are used because they were less easily seen by others. There are much better alternatives that solve visibility problems now.

Blended or "Invisible" Bifocals

The so-called blended bifocal follows the optical characteristics of the usual round-seg bifocal, except that the demarcation line between the

distance portion and the bifocal is obliterated by a polishing process that substitutes a narrow nonoptical transition area for the line of demarcation.

A blended bifocal is not a progressive addition lens. The only resemblance is that, in both lens designs, the near segment is not obvious. Optically, a blended bifocal performs the same as a standard bifocal because only two actual zones of focus exist: one for distance and one for near. Consequently, with the exception of the region of the blended zone areas, no aberration or unwanted cylinder is noticeable peripherally as is typically present with a progressive addition lens.

Distortion is produced around the bifocal segment by the blended area. This blended area varies in width from less than 3 mm to just under 5 mm, depending on the power of the add and the base curve (Figure 5.29). This area serves as the boundary of the bifocal and means that the lens is fitted the same way that the ordinary visible round segment bifocal is fit.

Because most blended bifocals are of the round seg type and because the blend is wider than the usual demarcation line, the bifocal may require a greater depression of gaze for reading. Manufacturers recommend fitting this bifocal 1 mm higher than is usual for other types of bifocals, just like the visible round segment bifocal. The frame used should provide sufficient space in its lower area to allow for comfortable reading.

At certain viewing angles, the segment may be slightly visible to an observer. The tendency for the lens segment to be slightly more visible may increase with an increase in either distance or near addition lens powers.

High-Powered Lenses

Looking away from the center of a high plus lens will cause decreased visual acuity because of peripheral lens aberrations.

For example, a regular, nonaspheric +12.00 D lens with a −3.00 D back surface curve will show a power of +11.40 D sph in combination with a −0.94 D cylinder at a point 25 degrees from the OC. Therefore, the farther from the central area of the lens a person looks, the greater will be the departure from the desired power. Since the power is increasingly affected as a person looks farther from the OC, it is desirable that the reading area of the lens be as close to the distance OC as possible. For these reasons, (1) a straight-top bifocal is more likely to meet this requirement than a round one, and (2) the higher the bifocal is placed in the lens (closer to distance OC), the better the optical requirements can be met.

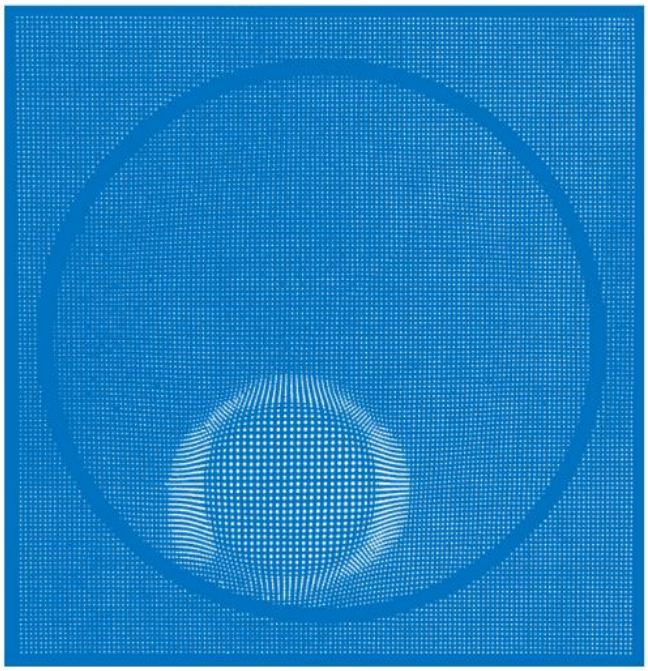


Figure 5.29 A blended bifocal is an alternative for those who desire an invisible near addition but do not want a progressive addition lens. (Courtesy of Essilor of America.)

Younger Children

Bifocals are seldom prescribed for younger children because of their inability to focus near point material. (Children can obviously see up close more easily than older adults.) More often, if a child needs a bifocal, it stems from a binocular visual problem. Children will normally see clearly through both distance or near portions when viewing near objects. Unless the seg height is properly placed, the child may unconsciously use the distance portion above the seg line for reading or near point work instead of the bifocal portion. To assure that the near addition is being used, unless the child is able to understand the use and purpose of the lens, the bifocal should be measured and placed so that the seg line *bisects* the pupil. For measuring purposes, the fitter should be on the same level as the child. This ensures that no parallax error occurs. Children adapt quickly and are not bothered by the high, mid-pupil seg placement.

The type of bifocal seg commonly used is a wide flat-top style. A wide near area helps to guarantee that the whole near field will be covered by the add, ensuring its prescribed use. (Some practitioners have used a progressive add lens for children who need a near addition because the seg is invisible.) If a progressive addition lens is used for children 7 years of age or younger, the fitting cross is placed 4 mm higher than normal (i.e., 4 mm above the pupil center). (For more on this topic, see Chapter 20, *Progressive Addition Lenses*, in the section entitled *Fitting Cross Heights for Children*.)

The above rule for children may not be applicable for older children who understand the purpose and use of the lenses. If the reason for using a bifocal or progressive addition lens with children is to retard the progression of myopia, it should be kept in mind that there are new and better alternatives available in contact lenses, spectacle lenses, and pharmaceuticals. Using conventional bifocals or progressive addition lenses for the purpose of controlling myopia may even have the opposite effect from what was intended! (See Chapter 18, *Lens Design*, in the section entitled *Myopia Control*.)

For a summary of factors that may cause needed changes to seg height, see Box 5.6.

Influence of Vertex Distance and Pantoscopic Angle on Apparent Seg Height

The apparent height of the segment is dependent on the distance that the lens is from the eye, or the vertex distance.

If a wearer complains that the new bifocals are too high and always in the way, yet from the front the segs look to be exactly the same height in relation to the eyes as the old pair, the lenses are very likely sitting farther from the face than the old ones were.

To illustrate, imagine standing 3 feet away from a window and looking over the window sill at the ground. Approaching the window, more of the ground can be seen, even though the actual height of the sill has not changed. The same is true of the dividing line of bifocals. If the bifocals are farther from the face, they interfere with vision just as if they were placed higher.

One solution is to decrease the vertex distance by changing the adjustment of the pad arms on frames that have pad arms. (See the section on nose pad adjustments in Chapter 9.) The other solution is to increase the pantoscopic angle of the frame, tilting the lower edge of the frame toward the face (Figure 5.30). The pantoscopic angle can

BOX 5.6 Possible Compensations for Segmented Multifocal Heights

Factors That May Affect Segment Height Placement	Possible Compensation
1. Head posture	Head back—seg lower Head down—seg higher
2. For tall persons	Seg lower
3. Seg height and occupational need	Office professions (close work)—seg higher Outdoor occupations (distance vision)—seg lower
4. For round and blended bifocals	Set segs 1 mm higher
5. For high plus lenses	Set seg tops as close to the distance optical center as practical
6. For younger children	Set bifocal seg tops at the level of the pupil center Set progressive addition lens fitting cross heights: 4 mm above pupil center for ages 7 or younger 2 mm above pupil center for ages 8 up toward the teen years For teen years, give consideration to setting the fitting height at the typical adult level

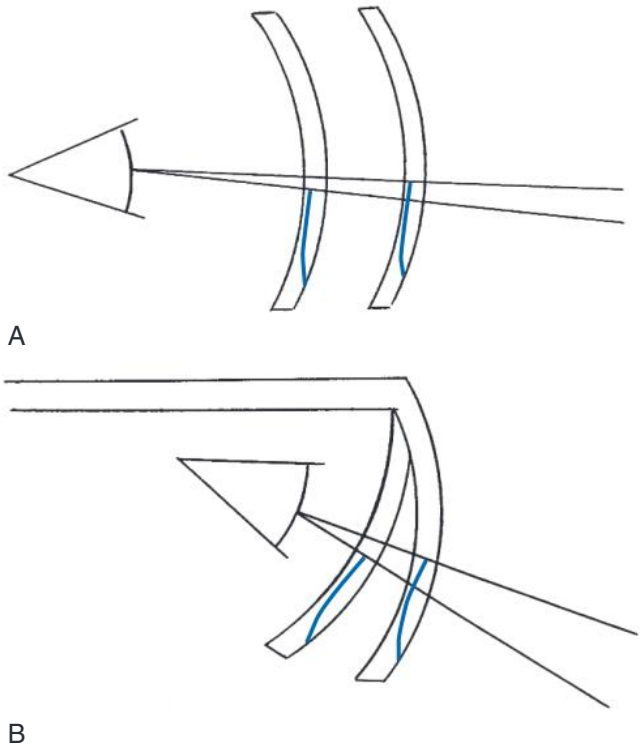


Figure 5.30 A, Decreasing the vertex distance of a lens will cause a reduction in the apparent height of the seg from the wearer's point of view. **B,** Increasing the pantoscopic angle of a frame also reduces the apparent seg height for the wearer.

BOX 5.7 Seg Adjustments Listed in Preferred Order

If Segs Seem High	If Segs Seem Low
1. Increase pantoscopic tilt	1. Narrow pads
2. Decrease vertex distance	2. Move pads down by adjusting pad arms
3. Spread pads	3. Increase vertex distance
4. Move pads up by adjusting pad arms	4. Reduce pantoscopic tilt
5.	5.

be increased on almost any type of frame and provides a workable solution because, to the wearer, the bifocal section appears to be lower when it is moved closer to the face. Vertex distance and pantoscopic tilt should routinely be checked when dispensing both segmented and progressive addition lenses. It should be noted that assuring minimal vertex distance and an appropriate pantoscopic angle are especially important for progressive addition lenses as the new viewing area will be noticeably increased.

Because of the relationship between apparent seg height and vertex distance, one seg will appear higher to the wearer than the other if one lens is closer to the face than the other. This possibility should always be investigated if the wearer complains of unequal seg heights (Box 5.7).

Prism-Compensated Segs

When a person has anisometropia (a large difference in power between the left and right eyes), unequal prism is induced when looking through any area of the lenses except the center. When reading, most people without anisometropia normally look both downward and inward. Because the distance lens powers are equal, the prism amounts for each of the two eyes are equal.

An anisometropic individual would have unequal amounts of vertical prism. Fortunately, an anisometrope who does not require bifocals is able to avoid a right/left vertical prism imbalance by turning the head downward, keeping the lines of sight of both eyes close to the OCs of the spectacles. The amount the eyes turn inward from these points is usually not of consequence. The movement is small enough to cause only a low amount of prism. The prism base is horizontal and is easily compensated.

If the wearer attempts to read by lowering the eyes rather than the lenses, the eyes will move away from the OCs and this will induce unequal amounts of vertical prism. This may be clinically significant. Some individuals with anisometropia, however, learn to compensate for this.

When an anisometrope is forced to use bifocals or trifocals, the prismatic consequences of the prescription can no longer be avoided because the reading segments are lower than the distance OCs. To predict if this will be a problem, ask the wearer to read through the old (nonbifocal) glasses. If the wearer drops the head to read, he or she is looking through the OCs and may need help in the form of slab-off prism to counteract the unequal prismatic effects. If, however, he or she drops the eyes to read and looks through the bottom of the lenses, the wearer is accustomed to reading through this portion of the glasses and will probably not need any prismatic compensation in the seg (see also Chapter 21).

COMPENSATING FOR AN INCORRECTLY SIZED SAMPLE FRAME

At the very beginning of the chapter, the importance of a properly positioned frame was emphasized. Before measuring for lens placement, the frame must be positioned on the face where it will be worn, otherwise

the measurements will be wrong. So with metal frames, the nose pads are positioned for proper height, and, as stated earlier, with plastic frames, if the bridge of the sample frame is too small, the frame will sit too high; if it is too large, it will sit too low. But what should be done if the sample frame is not the same size as the frame that will be worn? Unless allowances for frame size differences are made, the lens measurements will be wrong.

If the eye size is too large or too small, the depth of a given frame style will vary uniformly from one size to the next, according to the "boxing" concept of lens size. If the eye size is incorrect, the segment height ordered will need to be changed to allow for the difference in lens depth. When the difference in vertical dimension from one given eye size to the next is 2 mm, the change required in either the OC or seg position from the bottom of the eyewire is 1 mm.

When the Eye Size Is Incorrect

Suppose a person needs, for example, a 52□20 frame, but the closest available sample is 50□20. The bifocal is measured using the 50□20, and the height is determined to be 15 mm. If the lenses are ground for the larger frame, a 15-mm bifocal height will place the seg line too low. The question is how much higher must it now be placed?

To determine the answer, consider that a given frame may use the same pattern or tracing shape for all eye sizes. When the eye size is increased by 2 mm across the A dimension, there is effectively 1 mm of lens material being added to the outside edge in every direction (Figure 5.31). This means that the distance from the geometric center to the lower bevel will be increased by 1 mm. At the same time, the distance from the *desired* seg top position to the lower eyewire also increases 1 mm. Therefore, if a 50□20 frame requires that the seg line be 15 mm high, a 52□20 frame will mandate a 16 -mm high seg to maintain the location of the upper line at the desired level. By the same reasoning, a sample frame having an eye size 2 mm too large will measure 1 mm higher than actually required.

Rule of thumb: For an improper eye size, the seg height is corrected by one-half the difference between sample frame eye size and desired frame eye size.

As with any rule of thumb, exceptions do occur. Here are two:

1. If the bridge of the frame is constructed proportionally higher (or lower) in the frame as the eye size changes, the variations will not be constant.
2. Because of the wearer's nose-cheek formation, if it appears that a larger eye size will cause the inner, lower eyewire sections of the larger frame size to rest on a different anatomic part of the face, a larger eye size may rest higher on the face than might be expected or desired.

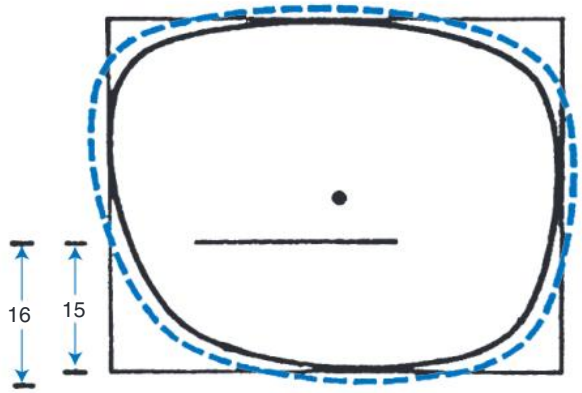


Figure 5.31 The actual sample frame eye size is represented by the *solid line*. The desired eye size to be ordered is represented by the *dotted line* and is 2 mm larger. Hence, the seg height to be ordered will be 1 mm greater.

If the Correct Bridge Size Is Unavailable

Now consider the case where the correct eye size is available, but the bridge is one size too small. It is still not possible to measure directly using the frame as it sits "normally" when placed directly on the face. When the bridge size is too small, the whole frame will sit too high on the face. Any uncompensated direct measure will result in a seg that is much too low. The right bridge size will allow the frame to be at its correct lower position. Unfortunately, there is no conversion factor possible using a sample frame with the wrong bridge size. Instead the fitter must move the frame down the nose until properly positioned and then hold it in place while measuring for seg height. (This presumes that the fitter is able to accurately estimate where the correct size will place the frame.)

The Alternatives

Of the two situations presented, the more predictably accurate involves an incorrect eye size combined with a correct bridge size. If the fitter has a choice between using either (1) an incorrect eye size and correct bridge size or (2) a correct eye size and incorrect bridge size, then the first instance should be chosen.

INSTRUCTING THE NEW BIFOCAL WEARER

New multifocal lenses represent a completely foreign experience for the first-time wearer. Some of the resultant problems may be prevented by direct advice ahead of time.

Because of the magnification produced by plus lenses, the wearer can expect objects seen through bifocals to appear magnified, creating the impression that these objects are closer because they appear larger. Curbs look higher than they really are, and staircases become real hazards when observed through the bifocal add. Distance judgment returns to normal after a period of adaptation despite the magnification, and the height of stairs, curbs, and so forth are properly judged.

The new bifocal wearer will experience differences from well-established habits, and the necessary adjustments to compensate for the differences should be explained to him or her.

For example, before wearing bifocals

1. The floor could be seen by keeping the head erect and dropping the eyes into the lower portion of the lenses.
2. A book could be read by looking through the center of the lenses and dropping the chin and head.

But to correctly use bifocals

1. The floor is seen by dropping the chin and head, looking through the center of the lenses.
2. A book must be read by holding the head erect and dropping the eyes into the lower portion of the lenses.

These differences may be contradictory to the wearer's well-established habits. A period of adaptation is required. The wearer can more easily master the new responses if he or she understands them ahead of time.

DETERMINING LENS BLANK SIZE

A *lens blank* is a lens before it has been edged to fit into the frame. It may be either finished or semifinished. A *finished* lens blank has the correct powers called for in the prescription with both front and back surfaces finished and ready to use. It needs only to be edged. A *semifinished* lens blank has only one side of the lens finished, usually the front side; the back side needs to be ground and polished to the correct power.

The dispenser is concerned with lens blank size for several reasons. For single-vision lenses, the question is especially pertinent if lenses are to be edged in-house. The lens blank size determines if an in-house edging lab will be able to edge the prescription from finished lenses that are in stock or if the prescription will have to be sent out for surfacing. For multifocal lenses, the question is, given the seg height and PD requested, can the lenses be made for the frame selected?

Secondarily, larger lens blanks are costlier and create more material waste during edging.

Minimum Blank Size (MBS) for Single-Vision Lenses

The PD *measurement* determines the position of the OCs of the lenses and helps decide the total size of the finished lens blank required for the designated frame. It can be recalled from Chapter 2 that the effective diameter (ED) of the spectacle lens is found by taking the distance from the geometric center of the lens to the edge point of the lens farthest from the geometric center and doubling it (see Figure 2.1). If a person's eyes are not at the geometric centers of the frame, the centers of the lenses must be displaced or decentered so they are horizontally and vertically aligned with the centers of the wearer's pupils.

For example, if the OC of the lens falls at the geometric or boxing center of the frame's lens shape, then a lens blank with a diameter equal to the frame shape's ED is large enough to fill the frame's lens opening. But if the lens must be decentered, then, as a general rule, 2 mm must be added to the ED of the lens blank for every 1 mm the lens is decentered. (Note: This rule holds true when the longest radius from the geometric center of the lens opening is opposite in position [nasal or temporal] to the direction of decentration. In other words, if the longest radius of the lens opening is temporal and the lenses are decentered inward [nasally], the rule holds true as it does if the longest radius is nasal and the lenses are decentered outward [temporally]. In the majority of cases, the longest radius will be temporal and lens decentration will be inward. So when calculating MBS, use the regular formula shown below.)

Using a Formula to Find MBS for Finished Single-Vision Lenses

MBS for finished, single-vision lenses can be summarized as a simple formula. The formula is:

$$\text{MBS} = \text{ED} + 2(\text{decentration per lens}) + 2$$

where MBS is the minimum blank size and ED is the effective diameter of the frame shape. The decentration per lens is the difference between the frame PD (A + DBL) and the wearer's PD, all divided by 2. Expressed as a formula, this is:

$$\text{Decentration per lens} = \frac{(\text{A} + \text{DBL}) - \text{binocular PD}}{2}$$

Twice the decentration per lens equals total decentration.

In other words,

$$\text{Total decentration} = (\text{A} + \text{DBL}) - \text{binocular PD}.$$

This means that the formula for MBS could also be written as:

$$\text{MBS} = \text{ED} + \text{total decentration} + 2\,\text{mm}$$

The last factor in the MBS formula is "+2 mm." These additional 2 mm add a slight amount of extra lens material to allow for possible defects on the edge of the lens. Here is an example of how to figure out the MBS for finished single-vision lenses.

Example 5.4

What would the MBS be for a finished, single-vision lens that is to be placed in a frame having the following dimensions?

$$\begin{aligned}\text{A} &= 52\,\text{mm}\\ \text{DBL} &= 18\,\text{mm}\\ \text{ED} &= 57\,\text{mm}\end{aligned}$$

The wearer's binocular PD is 62 mm.

Solution

First find total decentration.

$$\text{Total decentration} = (\text{A} + \text{DBL}) - \text{binocular PD}$$

In this case,

$$\begin{aligned}\text{Total decentration} &= (52 + 18) - 62\\ &= 8\,\text{mm}\end{aligned}$$

Now that the total decentration is known, MBS is determined by:

$$\begin{aligned}\text{MBS} &= \text{ED} + \text{total decentration} + 2\,\text{mm}\\ &= 57 + 8 + 2\\ &= 67\end{aligned}$$

Therefore, if the prescription has no prescribed prism, the smallest finished lens blank that could be used has a diameter of 67 mm.

Using a Formula to Find MBS Using Monocular PDs

If monocular PDs are to be used instead of binocular PDs, the MBS formula starts the same as it did when binocular PDs were being used. That formula was:

$$\text{MBS} = \text{ED} + 2(\text{decentration per lens}) + 2$$

But for monocular PDs, which are calculated separately for each lens, the decentration per lens is now:

$$\text{Decentration per lens} = \frac{(\text{A} + \text{DBL})}{2} - \text{monocular PD}$$

Example 5.5

What would the MBSs be for a finished, single-vision lens pair that is to be placed in a frame having the following dimensions?

$$\begin{aligned}\text{A} &= 52\,\text{mm}\\ \text{DBL} &= 18\,\text{mm}\\ \text{ED} &= 57\,\text{mm}\end{aligned}$$

The wearer's right monocular PD is 32 mm, and the left monocular PD is 30 mm. What is the MBS for right and left lenses?

Solution

First, find the decentration for just the right lens.

$$\begin{aligned}\text{Decentration per lens} &= \frac{(\text{A} + \text{DBL})}{2} - \text{monocular PD}\\ &= \frac{52 + 18}{2} - 32\\ &= 35 - 32 = 3\,\text{mm}\end{aligned}$$

Next, use the MBS formula:

$$\begin{aligned}\text{MBS} &= \text{ED} + 2(\text{decentration per lens}) + 2\\ &= 57 + 2(3) + 2\\ &= 65\,\text{mm}\end{aligned}$$

The right lens requires a 65- mm lens blank.

When the MBS for the left lens is calculated, first find the decentration per lens.

$$\begin{aligned}\text{Decentration per lens} &= \frac{(\text{A} + \text{DBL})}{2} - \text{monocular PD}\\ &= \frac{52 + 18}{2} - 30\\ &= 35 - 30\\ &= 5\,\text{mm}\end{aligned}$$

Next, use the MBS formula:

$$\begin{aligned}\text{MBS} &= \text{ED} + 2(\text{decentration per lens}) + 2 = 57 + 2(5) + 2\\ &= 69\,\text{mm}\end{aligned}$$

The left lens requires a 69-mm lens blank. This may seem confusing at first that the lens with a smaller monocular PD requires a larger lens blank. Yet the smaller the PD, the more the lens will need to be decentered and the bigger the lens will need to be to cover the frame's lens opening temporally.

Realistically, a lab can produce a single-vision lens for most any frame. So, the issue is not if it is possible to make the lens but how the lens might turn out.

Important takeaways are:

The larger the ED of the frame, the larger the lens blank that is required.
- As blank size increases for minus-powered lenses, so will the edge thickness.
- As blank size increases for plus-powered lenses, so will the center thickness. This results in heavier lenses and an increase in edge thickness for all but the thinnest point on the edge.

The more decentration that is required, the larger the lens blank becomes, with the same consequences for center and edge thicknesses as listed above.

For plus lenses, at times it may be wise to specifically ask the lab to make the lens as thin as possible. (This may require surfacing the lens from a semifinished lens blank.) For finished single-vision plus lenses, the lab may otherwise use a standard-sized finished lens blank, even if that blank is actually larger than required. A good example would be for children with small frames. Using a larger-than-needed lens blank can result in a lens that is considerably thicker than would be necessary.

For more on MBS for single-vision or multifocal lenses, see Brooks: *Essentials for Ophthalmic Lens Finishing.*[4]

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PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. True or false? When measuring for multifocal heights, the place on the eyewire directly below the pupil is used as a zero point.
   a. True
   b. False
2. The OC and the MRP are at exactly the same point on the lens except:
   a. when there is a measured MRP height.
   b. when there is prescribed cylinder present in the prescription.
   c. when there is prescribed prism present in the prescription.
   d. when a bifocal segment has a raise instead of a drop.
   e. The OC and the MRP are never at exactly the same point on a lens.
3. When the wearer's PD is less than the A + DBL measurements of the frame, then:
   a. positive face form is required.
   b. negative face form is required.
   c. no face form is required.
   d. pantoscopic tilt is required.
   e. retroscopic tilt is required.
4. You have a very small oval lens. The eye size is only 30 mm. The bridge size is 22 mm. The lens powers are −3.50 D sph. The wearer's PD is 62 mm. In practice, how would you adjust the frame for face form?
   a. a very slight amount of face form
   b. no face form
   c. a very slight amount of antiface or negative face form
   d. a moderate amount of antiface or negative face form
5. For every 2 degrees of pantoscopic tilt, the OC should be:
   a. raised 0.5 mm above the pupil center.
   b. raised 1 mm above the pupil center.
   c. lowered 0.5 mm below the pupil center.
   d. lowered 1 mm below the pupil center.
   e. There is no relationship between pantoscopic tilt and the vertical placement of the OC.
6. True or false? Tilting the wearer's chin back until the plane of the frame front is perpendicular to the floor and then marking the pupil height is a short cut measuring method for placing the MRP of the lens at the appropriate fitting height.
   a. True
   b. False

7. Here is a theoretical question. There are two frames. Both are for the same wearer. In fact, both are the same frame style and size exactly. However, one will be worn with no pantoscopic tilt. The other will have a lot of pantoscopic tilt. Which one should have the highest MRP when the lenses are ordered?
   a. The one with no pantoscopic tilt.
   b. The one with a lot of pantoscopic tilt.
   c. There should be no difference in ordered MRP height at all.
8. You measure the height to the pupil center to be 26 mm for your patient's chosen frame. The B dimension of the frame is 40 mm, and the pantoscopic tilt of the frame is 10 degrees. How high do you order the MRP?
   a. 26 mm
   b. 23 mm
   c. 21 mm
   d. 20 mm
   e. 15 mm
9. You measure an MRP height to be 26 mm. The B dimension of the frame is 44 mm, and the pantoscopic tilt of the frame is 12 degrees. How high should you order the MRP? (Watch out! This question may not be as straightforward as it appears.)
   a. 26 mm
   b. 24 mm
   c. 22 mm
   d. 20 mm
   e. 18 mm
10. The purpose of a distometer is to:
    a. measure the distance between lenses and the frame eye size.
    b. measure the power of a spectacle lens.
    c. measure the PD.
    d. measure the vertex distance.
    e. measure the segment height.
11. The left lens is closer to the face than the right lens. Therefore,
    a. the left seg will seem higher to the wearer than the right.
    b. the right seg will seem higher to the wearer than the left.
    c. there will be no effect on the apparent subjective height of the segs.
12. Which of the following is *not* a legitimate use of a Fresnel press-on segment?
    a. As an aide for determining segment height.
    b. As a temporary bifocal addition.
    c. As a means of changing the distance power of the wearer's existing glasses until such time as their new glasses arrive.
    d. To demonstrate how a double segment lens would work for occupational purposes.
13. For every 1- D increase in base curve, what happens to the vertex distance?
    a. It increases by approximately 0.6 mm.
    b. It decreases by approximately 0.6 mm.
    c. It increases by approximately 1 mm.
    d. It decreases by approximately 1 mm.
14. The wearer's glasses come back from the lab, but her lashes brush the backs of the lenses with each blink. She does not want to switch to a different frame, and you cannot alter the bridge. You have done everything you can by adjusting pantoscopic angle and face form. You still need 1 mm more of vertex distance to clear the lashes. You decide to reorder lenses with new base curves. How should you change the base curves?
    a. Increase the base curve by 1 D.
    b. Increase the base curve by 2 D.
    c. Decrease the base curve by 2 D.
    d. Decrease the base curve by 1 D.
    e. You cannot solve the problem this way. Change frames.
15. In measuring for a trifocal lens, we find the vertical distance from the level of the lowest portion of the inside bevel of the lower eyewire to the lower edge of the pupil to be 22 mm. What trifocal height should be ordered?
    a. 22.5 mm
    b. 23.5 mm
    c. 24 mm
    d. 20 mm
    e. 21 mm
16. How should round segment heights be ordered compared with flat-top segment heights?
    a. Round segment heights should be ordered 1 mm lower than flat-top segment heights.
    b. Round segment heights should be ordered 2 mm lower than flat-top segment heights.
    c. Round segment heights should be ordered 1 mm higher than flat-top segment heights.
    d. Round segment heights should be ordered 2 mm higher than flat-top segment heights.
    e. Segment shape has no influence upon segment height.
17. An individual wears 3 Δ base-up prism before the right eye and 3 Δ base-down prism before the left eye to alleviate a phoria problem. If an empty frame is used in measuring for bifocal height, what alteration in those measured values must be made?
    a. Raise the right bifocal segment 0.5 mm and lower the left bifocal segment 0.5 mm from their measured values.
    b. Raise the right bifocal segment 1 mm and lower the left bifocal segment 1 mm from their measured values.
    c. Lower the right bifocal segment 0.5 mm and raise the left bifocal segment 0.5 mm from their measured values.
    d. Lower the right bifocal segment 1 mm and raise the left bifocal segment 1 mm from their measured values.
18. An individual wears 2 Δ base-up prism before the right eye and a 2 Δ base-down prism before the left eye to alleviate a phoria problem. If an empty frame is used in measuring for bifocal height, what alteration in those measured values must be made? Choose the best answer from those given.
    a. Raise the right bifocal segment 1 mm and lower the left bifocal segment 1 mm from their measured values.
    b. Lower the right bifocal segment 1 mm and raise the left bifocal segment 1 mm from their measured values.
    c. Lower the right bifocal segment 1 mm from its measured value, and leave the left bifocal segment at the measured value.
19. Here is a prescription:
    R: −3.00 − 1.00 × 180 4 Δ base up
    L: −3.00 − 1.00 × 180 2 Δ base down
    You are ordering bifocals. With only dummy lenses in the frame, you measure the right bifocal height to be 19 mm and the left to be 18 mm. You are ready to order the lenses. Which of the following bifocal heights would be most acceptable? (Round to the nearest millimeter, but remember when rounding, the lenses work as a pair.)
    a. R: 19, L: 18
    b. R: 17, L: 19
    c. R: 21, L: 18
    d. R: 20, L: 17
    e. R: 18, L: 19

20. An individual selects a frame with the following dimensions:
A = 48
B = 44
DBL = 20
The wearer's PD is 62 mm, and the seg height is measured at 21 mm. The seg style chosen is a double-D occupational.
How much vertical near viewing area will there be at the top of the lens once the lenses are edged and inserted in the frame?
a. 6 mm
b. 8 mm
c. 10 mm
d. 12 mm
e. 14 mm

21. How should bifocal height be positioned for a child?
a. At the lower limbus
b. 1 mm below the lower edge of the pupil
c. At the lower edge of the pupil
d. At the center of the pupil
e. 4 mm above the center of the pupil

22. The seg position for the new glasses in a newer style frame should duplicate the seg position in the old pair of glasses. The old seg height was 14 mm. However, the bifocal line is 2 mm below the lower limbus. For the new frame, the distance from the lowest part of the inside bevel of the lower eyewire up to the level of the limbus is 18 mm. What bifocal height would you order for the new pair so that the new pair matched the old seg height?
a. 14 mm
b. 15 mm
c. 16 mm
d. 17 mm

23. True or false? To lower the apparent height of a bifocal segment from the wearer's perspective, it is possible to increase the panoscopic angle.
a. True
b. False

24. A person chooses a frame, but the eye size is too small. The sample frame has an A dimension of 48 mm with a 20- mm bridge size. The frame needed is 50 mm with a DBL of 20 mm. There is no frame of this size available. The frame must be ordered. It is still necessary to measure for progressive addition fitting cross height. The fitting cross height measured using the sample frame is 21 mm. What fitting cross height should be ordered?
a. 19 mm
b. 20 mm
c. 21 mm
d. 22 mm
e. 23 mm

25. A frame style is chosen by your patient. The only sample frame size you have is a 48-mm eye size and a 20- mm bridge size. The eye size is fine, but the bridge size should be 18 mm. You want to order the correct segment height for a bifocal lens. How would you do it?
a. Measure the seg height with the 48□20 sample frame on the patient exactly as it sits on the patient's face. Use that measure.
b. Measure the seg height with the 48□20 sample frame on the patient exactly as it sits on the patient's face. Subtract 1 mm from the segment height you measured and order that.
c. Measure the seg height with the 48□20 sample frame on the patient exactly as it sits on the patient's face. Add 1 mm to the segment height you measured and order that.
d. Hold the 48□20 frame higher up on the patient's face at the place you think it will rest with the smaller bridge size. Measure the seg height with the frame in that location and use that measurement.

26. A semifinished lens blank:
a. has both front and back surfaces already ground to the correct curves and power but has not yet been edged.
b. has been made to the correct thickness but does not have the correct surface powers on the front or the back surfaces.
c. has the front surface at the correct curve, but the back surface is not yet ground to the needed curvature to produce the required lens power.

27. A frame has the dimensions of 49□19 with an ED of 52 mm. The patient's PD is 68 mm. What is the minimum lens blank size required?
a. 50 mm
b. 52 mm
c. 54 mm
d. 63 mm
e. 71 mm

28. An oval-shaped frame has an eye size of 52 mm, a bridge size of 18 mm, and a B dimension of 38 mm. What is the ED of the frame?
a. 48 mm
b. 50 mm
c. 52 mm
d. 56 mm
e. 63 mm

29. What is the smallest lens blank size possible for a 50- mm round eye size frame if the lens must be decentered 3 mm per lens?
a. 50 mm
b. 52 mm
c. 54 mm
d. 56 mm
e. 58 mm

6

Ordering and Verification

ORDERING

There are several ways to order spectacle lenses from an optical laboratory. These include:

- Filling out a printed laboratory order form and sending it to the optical laboratory with the frame to be used. If there is an in-house optical laboratory, the paper form may travel with the lens and frame materials during laboratory processing.
- Calling in information to the lab over the phone.
- Entering the needed information online using the optical laboratory's web site.
- Electronically transferring prescription information from the office's electronic health records system directly to the optical laboratory's computer system. Using a data entry system may help to prevent errors or omissions in processing, since the order may not process with incomplete information.

With paper forms, it is very important to print the necessary information. Poor or illegible handwriting usually results in errors.

General Procedures for Forms

When ordering less than a total frame and both lenses, specify this clearly. For printed forms, write this in large letters or check the appropriate places on the form.

Do not include unneeded data or information on any forms if such information is not necessary or applicable to the order.

Lens Information Protocol

When writing the lens prescription in paragraph form, such as in a letter, always write the data referring to the right lens first followed by the data for the left lens. For example, "Mr. Hensley was issued a prescription of OD: −3.00 D sph, OS: −2.75 −1.50 × 175." When written on a blank prescription pad, this same prescription would be written with the left lens value directly below that of the right lens. This would appear as follows:

OD : −3.00 D sph

OS : −2.75 − 1.50 × 175

"OD" is, in this instance, the abbreviation for "right eye" from the Latin words *oculus dexter*, whereas "OS" is the abbreviation for the Latin words *oculus sinister*, or left eye. Using an *R* and an *L* instead is perfectly acceptable.

Always use at least three digits for each of the sphere, cylinder, and axis components. If the dioptric unit is less than 1.00 D, use a zero before the decimal point, as for example, +0.75 D. Carry figures two places after the decimal point, as for example, +2.00 D (not +2 D) or −1.50 D (not −1.5 D). State the axis as *x*, but do not put a degree sign after the numbers representing the cylinder axis because it may be mistakenly read as an extra zero. For example, 10 degrees may be misread as 100 when written out with the degree sign in longhand as 10°. To avoid confusion, it is advisable to use three numbers for the cylinder axis. Therefore, it is normal to see a 5-degree axis written as 005.

Always put either a plus or a minus sign in front of the lens power. In regular mathematics, a number written without a plus sign is assumed to be plus. When recording powers for spectacle lenses, never leave off the plus sign.

When ordering or writing in 1/8 diopter steps, by optical prescription-writing convention, 1/8 diopter steps are truncated to two decimals. For example, 1/8 diopter is ±0.125 D. However, it is written 0.12 D. Three-eighths would be written as 0.37 D, 5/8 as 0.62 D, and 7/8 as 0.87 D. (When doing calculations, remember that there is a hidden 5 out in the thousandths place that was truncated in spectacle notation. You will need to put that hidden 5 back in the number if you want the math to come out exactly.)

Check the base curve of the wearer's old lenses, particularly when only one lens is being replaced. This is not to say that the same base curves as were used for the old lenses should be ordered for a completely new prescription. (For information on how to measure base curves, see Chapter 13. This same chapter also explains when and why one should or should not use the same base curves as were previously used.)

Frame Information

All information about the frame including size, color, frame name, and manufacturer should be on the order, even if the frame is sent along with the order. This is helpful in assuring that the order is correct, the frame can be reunited with the order should it get separated, and for reference if a prescription needs to be replaced in the future.

REORDERING FROM EXISTING SPECTACLES

Sometimes, it is necessary to use a person's existing spectacle lenses as the basis for ordering another pair of glasses. This can occur in an emergency if the person has a cracked or broken lens and the lenses are still in the frame. It may also happen that an individual has a pair of glasses and wants a second pair but no longer has the written prescription.

Obtaining Lens Information for Existing Spectacles

Although it is possible to read the prescription directly from the current eyeglasses, it is best to contact the prescriber or previous dispenser to verify what was ordered—not just what was received. For example, when taking a prescription from an existing pair of glasses, one may misread a cylinder axis as 170 degrees, when the lens is really an axis 168 degree lens. Yet, the original order could have called for an axis 165 degree lens. So an axis 170 degree lens is ordered. But what if the new lens comes in as an axis 172 degree lens? The dispenser will likely accept the lens because it is only 2 degrees off and within acceptable American National Standards Institute (ANSI) standards. When

the order comes back from the lab, what the dispenser does not realize is that, compared with the original prescription, the axis of the lens is really off by 7 degrees!

Take New Facial Measurements

Even when duplicating an old pair of glasses, it is still important to take new facial measurements. Retake the wearer's interpupillary distance (PD). You may still wish to use the distance between the optical centers (OCs) found in the old glasses, but you need to know the wearer's measured PD. Large differences may indicate the presence of prescribed prism.

If the lenses are either bifocal or trifocal lenses, note where the segment line falls in reference to the lower limbus. This is important if the new segments are to match the old ones. If the lenses are progressive addition lenses, find the location of the fitting cross on the old lenses to verify that it falls in the center of the pupil (see Chapter 20, *Progressive Addition Lenses*).

When the Wearer's PD Does Not Match the Distance Between Optical Centers

If the newly measured wearer's PD does not match the distance between the OCs in the glasses that are being worn, the dispenser's best options are to:

1. Find out where the prescription originated and call to verify the prescription. Specifically ask if the prescription contains prescribed prism. This is always the correct first option, even when the prescription can be easily read from the existing glasses, since an error still may have occurred.
2. If the wearer does not know where the prescription originated and does not want a new eye examination, use the distance between OCs found in the existing glasses,[1] even if it does not match the wearer's PD. You cannot be sure that prism caused by a difference in the wearer's PD and the separation between OCs is not part of the original prescription. This is the reasoning for duplicating what is currently being worn. (Besides, changing an existing prismatic effect may present adaptation problems for the wearer.) You should be certain that the reason for ordering a PD for the new glasses other than the wearer's measured PD is well documented in the record.

[1] **An exception to this rule:** The exception to this generalized rule would be for lenses that have very low powers in the horizontal meridian. If the optical center (OC) of a very low powered lens is off, there is very little horizontal prismatic effect produced. (This possibility will become more obvious once the reader is familiar with the American National Standards Institute Z80 standards for PD and horizontal prism.) For low-powered lenses, the distance between OCs can mismatch the wearer's ordered PD by a relatively large amount and still produce only a negligible horizontal prismatic effect. When this occurs, the glasses are still considered to be acceptably within tolerance.

For example, a lens pair has a power of −0.50 D sph in both eyes. The wearer's PD is 60 mm. However, the measured distance between lens OCs in the old glasses is 64 mm. This means that the resulting prismatic effect will only be 0.20 prism diopters for both right and left eyes combined. Unwanted horizontal prism of this amount is well within ANSI standards of acceptability. It is also highly unlikely that the original prescription included prescribed prism of less than even 1/4 diopter.

To summarize, familiarity with ANSI standards for PD-horizontal prism will make it easier to discern when differences such as these are due to allowable tolerances and when there is truly prescribed prism present in the existing prescription.

Obtaining Prescription Information for Single-Vision Lenses

The heart of the lens prescription is the sphere, cylinder, and axis. These measures of lens power are found using a *lensmeter* (Figure 6.1). Most lensmeters use line targets, but others have targets consisting of a circle of dots. There are lensmeters with internally viewed targets and those with targets projected on a screen. Lensmeters may also work manually or automatically. The vast majority of manual lensmeters use a crossed-line target.

How to Avoid Scratching the Lenses When Using the Lensmeter

Unfortunately, it is not difficult to scratch a lens on either the front or the back surface when using a lensmeter. This is because the back surface is against the lensmeter aperture and the lens is held secure with a spring-loaded lens clamp against the front surface. Here are some precautions to take.

- Always pull the lensmeter's lens clamp off the lens when repositioning the lens.
- Sliding the lens in the lensmeter without removing clamping pressure increases the likelihood of scratching front or back surfaces. These scratches are hairline scratches and noticeable to the wearer. Scratching can be a risk both when moving the lenses to spot the OCs and when sliding the lenses to check for unwanted horizontal prism.
- Some find it helpful to purchase foot-care corn pads from a drug or grocery store.[1] These are small round, self-adhesive pads with a hole in the center. The hole is about the same size as the lensmeter aperture. Placing this soft pad over the lensmeter aperture can guard against back-surface lens scratches. Pads need to be replaced periodically as they may pick up abrasive dirt over time. (Such pads do have some thickness. Therefore, power readings for high-powered lenses may be affected because of the slight increase in distance between the lensmeter aperture and the lens surface. In such instances, remove the pad, take the reading, and then replace the pad.)

How to Find Single-Vision Lens Powers Using a Crossed-Line–Target Lensmeter

When using a manual lensmeter, begin by focusing the eyepiece to assure an accurate reading. When focusing the eyepiece, imagine sitting on top of a tall building and looking at the street below. This will help relax your accommodation and keep your eye from changing focus, which can contribute to inaccuracies. First, rotate the eyepiece so that it moves toward the operator's eye—away from the rest of the instrument. Then looking at the *crosshairs and concentric circles* (not the crossed-line, illuminated target), slowly turn the eyepiece back toward the rest of the instrument until the crosshairs and concentric circles *first* come into sharp focus. If you turn too far and pass the first clear focus, again rotate the eyepiece away from the instrument; then, slowly rotate it back toward the instrument to the first best focus.

The focusing procedure is only done once and need not be repeated for each pair of spectacles being measured. However, this eyepiece focal adjustment will be different for each individual. When more than one person uses the instrument, the procedure must be repeated for each individual. (Time may be saved by having each person who regularly uses the instrument mark the edge of the eyepiece for his or her own "zero point.")

If a prism-compensating device is present on the instrument, this is also a good opportunity to make sure it is set for zero.

With which lens do I start?. When reading a spectacle lens prescription, which lens should be verified first? Here is how to decide.

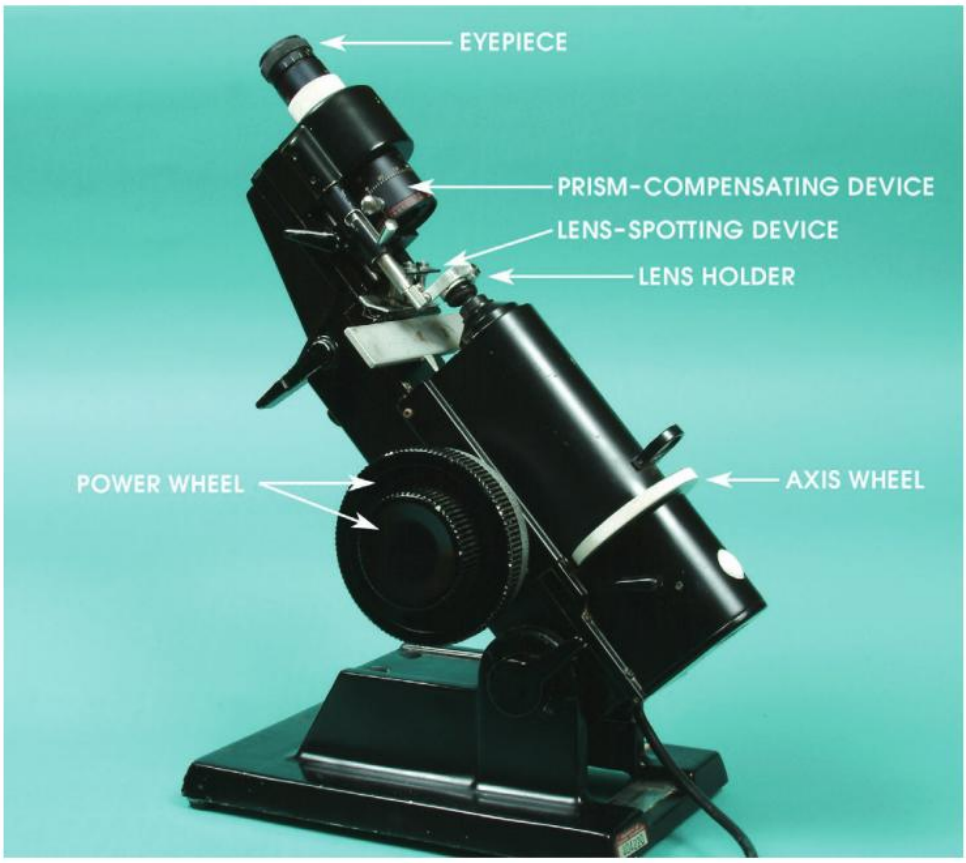

Figure 6.1 A manual lensmeter has certain basic parts common to most instruments.

- It is proper to begin with the strongest lens first. For this purpose, the strongest lens is defined as the lens with the strongest power in the 90-degree meridian.
- If the lenses have similar powers and there is also prescribed vertical prism in the prescription, then begin with the lens with the most prescribed vertical prism.
- If it is not evident which lens is stronger and there is no prescribed vertical prism, begin with the right lens.

Place the glasses in the lensmeter so that the back side of the lens is against the lensmeter aperture.

There are two ways to read or write a prescription. One is to read the cylinder in the prescription as a minus cylinder. The other is to read the prescription so that the cylinder is given as a plus power. We will first consider the prescription as being a *minus cylinder form* prescription.

Reading a lens in minus cylinder form. To read a prescription in minus cylinder form, begin by turning the *power wheel* in the high plus direction. Now slowly turn the wheel back in the minus direction. If the prescription is a sphere with no cylinder component, the illuminated target will clear all at once as shown in Figure 6.2. In older instruments, the target may consist of a single line, which represents the sphere crossed by three widely spaced lines, which represent the cylinder. A more common configuration consists of three closely spaced lines representing the sphere crossed by three widely spaced lines representing the cylinder.

If the prescription contains a cylinder component, the sphere and cylinder lines will not focus simultaneously. Thus, after the power wheel has been turned to the high plus, slowly turn the power wheel in the minus direction. This will cause either the sphere or the cylinder lines to begin to clear. *The sphere lines need to be cleared first.* If the narrower sphere lines begin to focus first, but do not fully clear, the *axis*

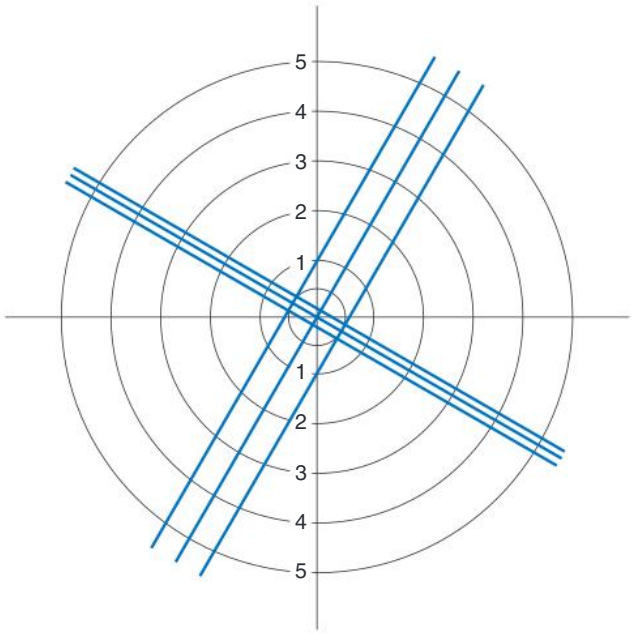

Figure 6.2 When the illuminated target shows both sphere and cylinder lines that are both clear at the same time, the lens is a sphere.

wheel should be turned until the sphere lines do clear (Figure 6.3). (It may be necessary to alternately adjust both the power wheel and the axis wheel until the sphere power lines do clear.) If the cylinder lines begin to clear first, the axis wheel should be rotated 90 degrees, causing the sphere and cylinder lines to transfer places. The sphere lines will

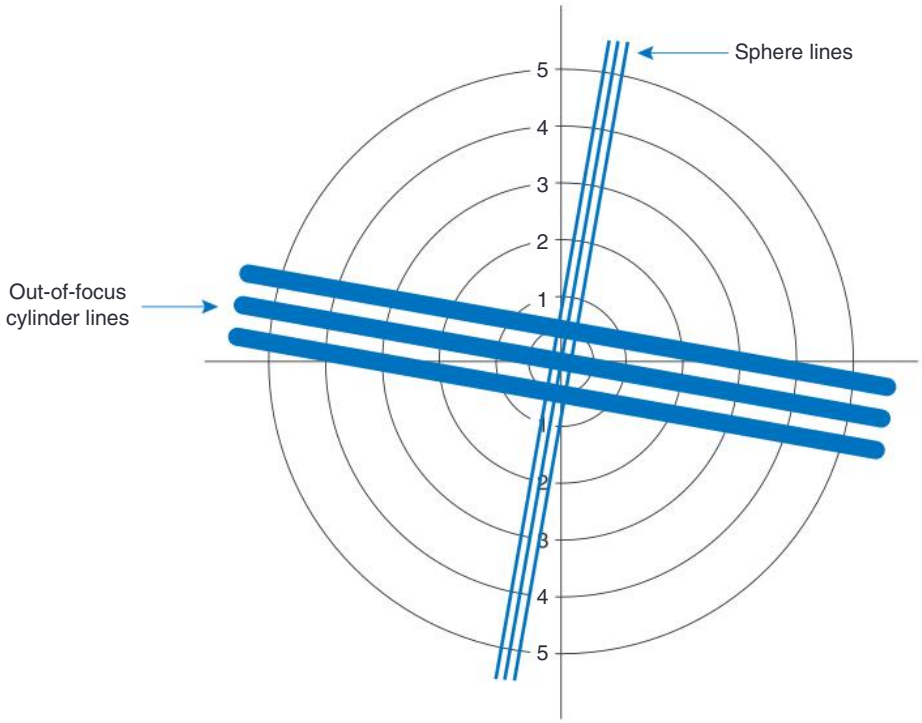

Figure 6.3 Whether the operator is reading a spherocylinder lens in plus or minus cylinder form, the sphere lines must come into focus before the cylinder lines.

then be clearer than the cylinder lines. When the sphere lines appear clear and unbroken, the value indicated on the power wheel is recorded as the spherical power of the prescription. Note the value seen on the axis wheel, and record this value as the cylinder axis.

Example 6.1

A lens has an unknown power. Find the sphere power of the lens and the axis of the cylinder when the prescription is to be written in minus cylinder form.

Solution

The power wheel is turned into the high plus then back into the minus direction. The target does not begin to clear until the power wheel is well into the minus. When it does begin to clear, the three cylinder lines are clearing first instead of the sphere lines. The axis wheel reads approximately 45 degrees. To make the sphere and cylinder lines change places, the axis wheel is rotated approximately 90 degrees. Now the axis is at about 135 degrees, but the sphere lines are still not quite clear. Rather, they appear to be diagonally broken (Figure 6.4).

Lines that appear broken and run diagonally to their intended course indicate that the target lines are not in the proper axis position. The axis wheel is rocked back and forth while the power wheel is "fine-tuned" until the lines are restored to continuity. (A final reading with the power wheel is done by moving the wheel from the minus to the plus direction[2] and then stopping when the lines are *first clear*.) In this example, the sphere lines become clear when the power wheel reads −4.00 D and the axis wheel reads 135 degrees. These first two parts of the prescription are written as shown in Figure 6.5, *A*.

Example 6.1 continued

In the example given earlier, we had found a sphere power of −4.00 D and a cylinder axis of 135 degrees. Find the power of the minus cylinder.

Solution continued

Now we continue by turning the power wheel farther in the minus direction. The sphere line blurs, and the cylinder lines begin to come into focus. When the power wheel reaches −4.75 D, the cylinder lines are clear. The power of the cylinder is the difference between the first and second power wheel readings. The difference between −4.00 and −4.75 D is 0.75 D. Because the procedure is for a minus cylinder lens, the cylinder power is recorded as −0.75 D. This is shown in Figure 6.5, *B*. (See Box 6.1 for a summary of this procedure.)

Finding the cylinder power. To find the cylinder power, continue turning the power wheel farther in the minus direction. The sphere lines will blur, and the three wide cylinder lines will come into focus (Figure 6.6). When the three cylinder lines are in focus, note the new power wheel reading. The difference between the sphere reading and this new reading is the power of the cylinder. This cylinder value is recorded as a negative number.

Reading a lens in plus cylinder form. Some prescriptions are written with the cylinder as a plus value instead of a minus value. When written this way, the prescription is said to be in *plus cylinder form*. To read a prescription in plus cylinder form, lensmeter measuring procedures are basically the same as when reading in minus cylinder form, with one exception. When finding the sphere power, turn the lensmeter power wheel first in the high *minus* direction, instead of the high plus direction. When the target is blurred out and the power wheel is in high

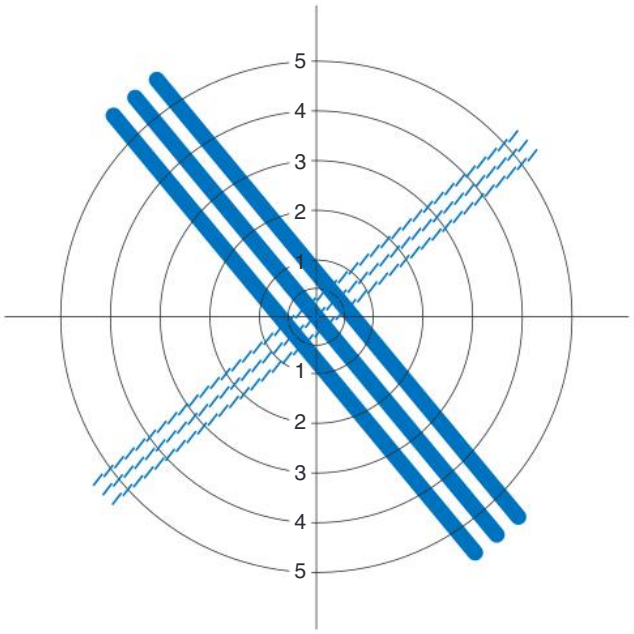

Figure 6.4 If the sphere lines will not focus and appear to be diagonally broken, the axis of the cylinder is off. Turn the axis wheel until the sphere lines sharpen. When the sphere lines sharpen, the axis is being read correctly.

	Sphere	Cylinder	Axis
R:	–4.00		135
L:			

A

	Sphere	Cylinder	Axis
R:	–4.00	–0.75	135
L:			

B

Figure 6.5 **A,** When recording the power of a prescription while reading a lensmeter, the first two components to read are the sphere and cylinder axis. These two numbers may be recorded immediately. **B,** After the sphere wheel is turned to find the power in the second meridian, the difference between the first and second sphere wheel readings is recorded as the cylinder power.

minus numbers, slowly turn the wheel back in the plus direction. If the prescription is a sphere, the illuminated target clears all at once. If the prescription contains a cylinder component, however, the sphere lines must come into focus first. Turn the axis wheel to achieve this. Sphere and cylinder axis may be recorded. (Note that the cylinder axis will be 90 degrees away from what it was when the lens was recorded in minus cylinder form. The sphere value will also be different.)

Next, turn the power wheel further in the plus direction until the three cylinder lines are clear. The difference between the sphere power reading and this new reading is the cylinder power. The cylinder power is recorded as plus. (Note that the numerical value of the cylinder is the same, whether recorded as plus or minus cylinder power, only the sign is different.)

For more on how to transpose from the plus to minus cylinder form of prescription writing, see the *Toric Transposition* section in Chapter 12.

Find and spot the optical center of the lens. After finding the sphere, cylinder, and axis, locate the OC of the lens by centering the illuminated target at the intersection of the cross hairs in the eyepiece reticle. This is done by moving the glasses left or right on the instrument table and moving the instrument table up or down. (In practice, this is done at the same time as sphere, cylinder, and axis values are being found.) Once centered, the lens is spotted using the lensmeter spotting mechanism.

If the cylinder power is high, the sphere and cylinder lines cannot be seen simultaneously. This makes centering of the lens difficult. To center the lens, move it until the sphere line crosses the center of the reticle cross hairs. Then focus the cylinder lines and recenter the lens so that the middle cylinder line crosses the center of the cross hairs. Then repeat the process, going back and forth between sphere and cylinder lines until both are centered without moving the lens.

After the first lens is spotted, move the second lens in front of the lensmeter aperture and determine sphere, cylinder, and axis values for the second lens. Locate the OC of the second lens by centering the target on the reticle horizontally. Do not try to center the lens vertically. Do not move the instrument table up or down.

If the target is not centered vertically, record the amount of resulting vertical prism seen in the instrument. (How prism is recorded will be explained in more detail later.) Spot the lens once. Now move the instrument table up or down until the target is centered vertically. Spot the lens a second time. The second spotting shows the OC height. It will also be used later to tell if the prescription is within standards for unwanted vertical prism. The first spotting is used to measure the horizontal distance between left and right OCs.

If there is no prescribed prism in the prescription, this horizontal distance between OCs should equal the wearer's PD. In practice, there is a certain amount of allowable tolerance for error. Tolerances are covered in this chapter in the section on lens verification.

The heights of the OCs are measured as the vertical distance from the lowest portion of the lens bevels up to the level of the spotted OC. When there is no prescribed prism present, the OC and MRP are one and the same. When this is the case, measuring OC height is the same thing as measuring MRP height.

BOX 6.1 How to Find Spherocylinder Lens Power Using a Standard, Crossed-Line–Target Lensmeter

1. Focus the eyepiece.
2. Turn the power wheel into the plus until the illuminated target blurs out.
3. Turn the power wheel slowly in the minus direction until the sphere lines clear.
4. Adjust the axis wheel for optimum sphere line unbrokenness and clarity.
5. Record sphere power and cylinder axis.
6. Turn the power wheel farther in the minus direction until the cylinder lines clear.
7. Take the difference between the two power wheel readings and record as a minus cylinder.

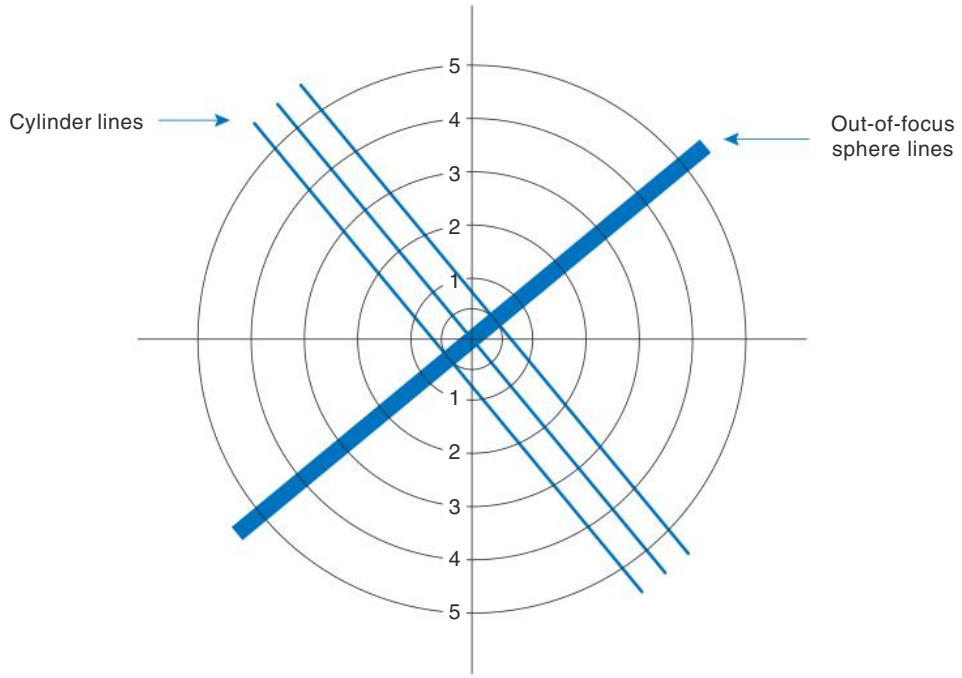

Figure 6.6 Once the cylinder lines are clear, cylinder power can be calculated. Cylinder power is the difference between the current power wheel reading and the reading noted earlier when the sphere lines were clear.

Obtaining Prescription Information for Multifocal Lenses

Distance powers for multifocal lenses are measured in the same way that powers for single-vision lenses are measured. A multifocal lens differs from a single-vision lens because it has additional plus power for viewing at near. This near addition is plus power that is added to the power of the distance prescription.

To measure the distance power of multifocal lenses, place the glasses in the lensmeter in exactly the same way as would be done for single-vision lenses (Figure 6.7). The distance power is measured in the manner previously described for single-vision lenses.

To measure the add (near addition) power, how the add is measured depends upon whether the add is found on the front or the back surface of the lens. We may think of the add as just a small plus-powered lens attached to either the front or the back surface of the distance-correcting lens. At the time of this writing, for most segmented multifocal lenses the add is found on the front of the lens.

Figure 6.7 To measure the power of single-vision lenses or the distance power of segmented multifocal lenses, the glasses are placed in the lensmeter as shown. This measures the prescription in the correct manner. The power being measured is known as the *back vertex power*.

Measuring Add Power When the Add Is on the Front Surface of the Lens

To measure the add power when the add is found on the front of the lens, turn the glasses around backward in the lensmeter so that the front of the lens is against the lensmeter aperture. (This is true for both multifocal and front-surface progressive addition lenses.) Now remeasure the distance power. When measured this way, the power is called *front vertex power*. When measured from the back in the normal way, the power measured is called *back vertex power*. (Progressive addition lenses with the add on the back are measured using back vertex powers.) For higher lens powers, it is not unusual to find a difference between front and back vertex powers. This is especially true of higher plus-powered lenses.

It will be noted that the lensmeter-measured cylinder axis for the front vertex power is the mirror image of the axis for the back vertex power. In other words, a lens having a 30-degree back-vertex-power axis will manifest an axis of 150 degrees when turned around.

When remeasuring the distance power as front vertex power, do not measure the lens at the OC. Instead measure the distance front vertex power at a location above the OC. That point should be as far above the OC and as far outward as the point where the add power will be measured is below the OC and inward (Figures 6.8 and 6.9). This technique ensures that any power variations caused by lens aberrations or lens thicknesses will be the same in distance and near power measurements.

Next, measure the power of the lens through the near segment (Figure 6.10). (For a summary of measuring near add power, see Box 6.2). The difference between distance and near power readings is the power of the near addition. When the lens is a spherocylinder lens, the near addition is the difference between the distance and the near power components. When finding this difference, the ANSI Z80.1 standard recommends, "For manual focimeters [lensmeters], both measuring points shall use the most vertical lines of the target as the criteria for determining the add power."[2] In other words, don't just automatically choose the sphere powers (sphere lines). It is possible to use either the

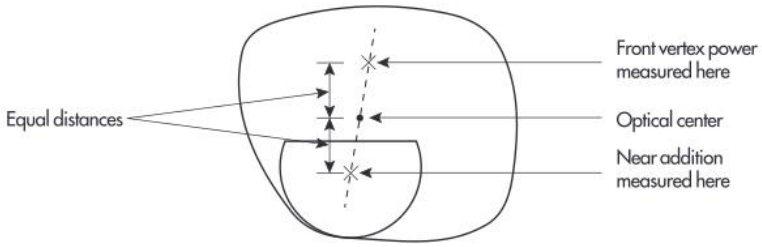

Figure 6.8 When measuring the add power of a lens, first turn the lens around. Remeasure the distance power at a point above the optical center. This point should be as far above the distance optical center as the near verification point is below the optical center. This point should also be outset as far as the near verification point is *inset*. The three points should line up on a *straight line* as shown by the *dashed line* in the diagram. This assures that any aberrations caused by the distance lens will be equal.

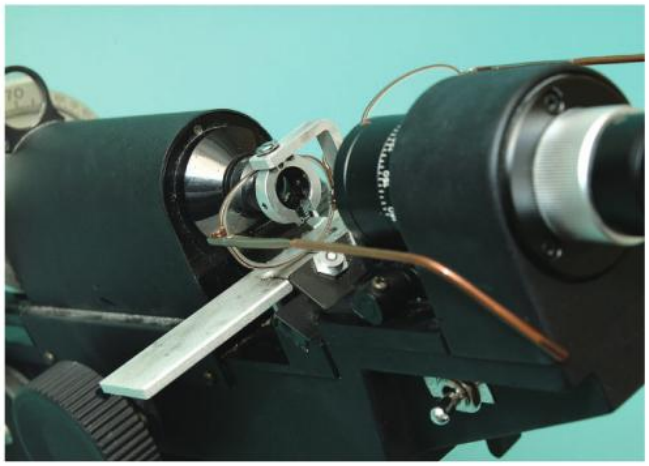

Figure 6.9 To measure multifocal lens power, the glasses must be turned around backward in the lensmeter and distance power measured again, this time as front vertex power. Note that the power is measured at a point as far above the optical center of the lens as the near verification point within the multifocal segment is below the distance optical center of the lens.

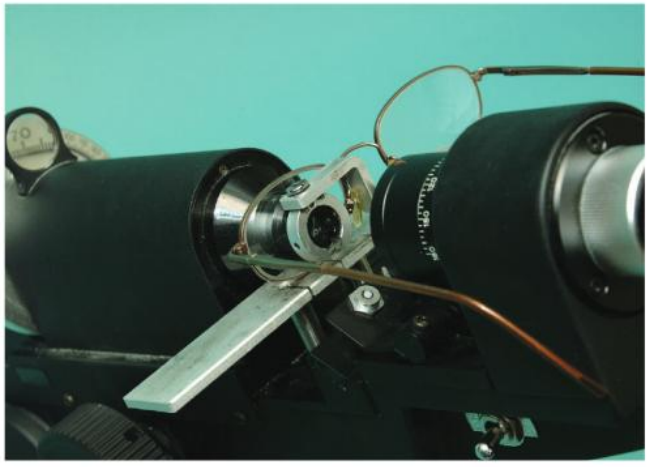

Figure 6.10 With the glasses still backward, the power through the multifocal segment is measured. This difference between distance and near powers is the power of the near addition.

difference in sphere line powers or the difference in cylinder line powers. The answer will come out approximately the same for both. However, for greater accuracy, choose the set of lines in the lensmeter that is most vertically oriented.

BOX 6.2 How to Measure Multifocal Add Power When the Add Is on the Front

When the Near Segment Is on the Front Surface

1. Turn the glasses around backward in the lensmeter.
2. Measure the most vertical lines of the *front* vertex distance power.
3. Measure the most vertical lines of the *front* vertex near power.
4. The difference between the two values is the add power.

When the Near Segment Is on the Back Surface

1. Leave the glasses in the lensmeter in the normal position.
2. Measure the most vertical lines of the *back* vertex distance power.
3. Measure the most vertical lines of the *back* vertex near power.
4. The difference between the two values is the add power.

Example 6.2

A lens has a distance front vertex power that reads +3.87 −1.00 × 020. The front vertex power through the near addition reads +5.87 −1.00 × 020. What is the add power?

Solution

The add power is +2.00, because +5.87 − (+3.87) = +2.00. The sphere power through the add is 2.00 D higher than the sphere power through the distance portion.

Sometimes when lens powers are high, it is difficult to see both sphere and cylinder lines through the add at the same time. It may only be possible to see the cylinder lines through the near segment and not the sphere lines. This happens because of the prismatic effect that is manifested since we are looking at a point away from the center of the lens. Nevertheless, it is still feasible to find the near addition power. Simply take the difference between the distance power wheel reading and the near power wheel reading using the cylinder lines. In this example, the cylinder lines in the distance are clear at +2.87 D. At near, the cylinder lines will be clear at +4.87 D. The difference is still the same +2.00 D add power as would be found using the sphere lines.

If the prismatic effect of the decentered lens causes the entire illuminated target to disappear off the viewing area, it may be necessary to use an auxiliary prism or a prism-compensating device to bring it back into view. The use of auxiliary prisms or a prism-compensating device is described later in the chapter.

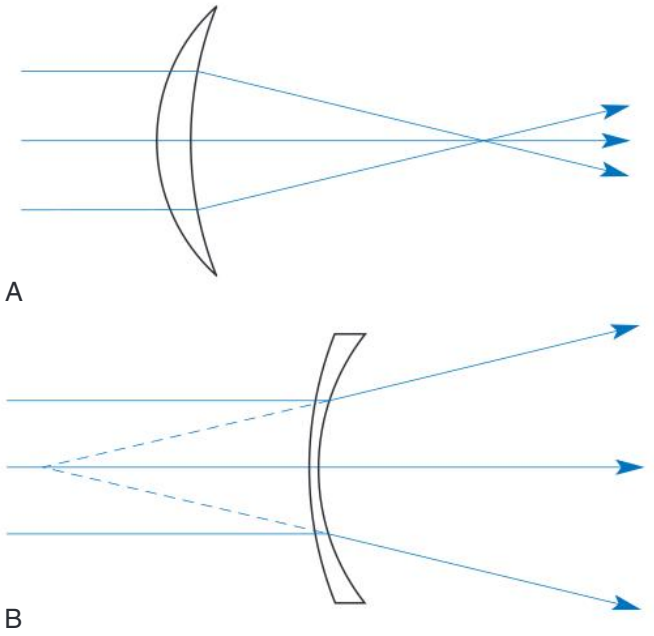

Figure 6.11 A distance lens is meant to meet the needs of either a farsighted eye using a plus lens **(A)** or a nearsighted eye using a minus lens **(B).** This is done by taking parallel light from a distant object and bringing it to focus at the far point of the ametropic eye. (An ametropic eye is one that has a refractive error and requires a lens prescription for distance vision.) A lensmeter is made to optically position the illuminated target at that far point. The light from the illuminated lensmeter target travels backward through the lens from right to left. (Remember that light rays are reversible. They will take the same path when traveling in the opposite direction.)

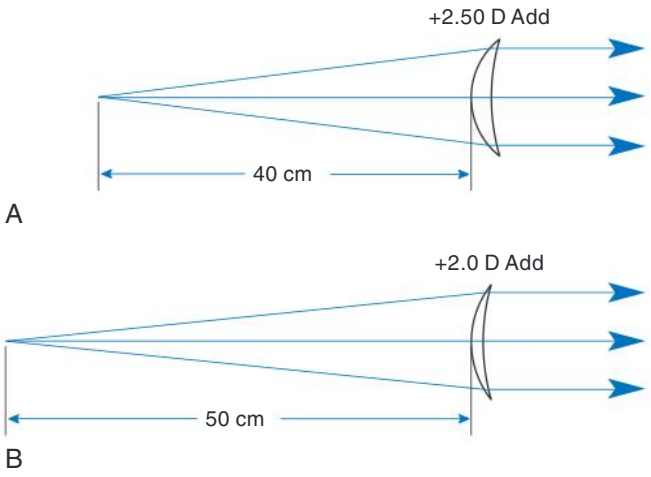

Figure 6.12 The small added plus lens (which becomes the near addition) will change diverging light rays from a near object and make them diverge less. To test for front-surface add power accuracy, the reference is in front of the lens, making front vertex power the correct power measurement. Both a +2.50 D add **(A)** and a +2.00 D add **(B)** will cause light diverging from their respective focal points to appear as if coming from optical infinity.

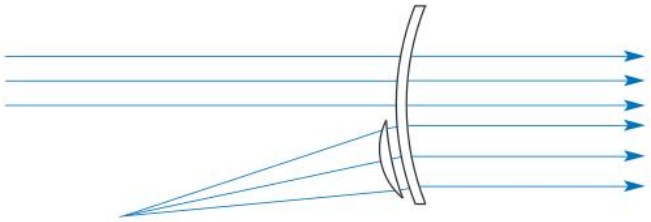

Figure 6.13 When a near object is located at the focal point of the near addition, diverging light is caused to leave the segment as parallel rays. When rays enter parallel, the emmetropic eye does not have to accommodate in order to see clearly. (An emmetropic eye has no refractive error and does not require any distance prescription.)

Why Spectacles With Front-Surface Adds Should Be Turned Around to Measure the Add Power

The purpose of a distance lens is to take parallel light and bring it into focus. For a plus lens, this will be a real image (Figure 6.11, *A*), and for a minus lens, this will be a virtual image (see Figure 6.11, *B*). To measure this type of lens, the illuminated lensmeter target is optically placed at the focal point of the lens. The light from the lensmeter target travels from behind the lens, going through the back of the lens and out the front. When the light comes out the front of the lens, the rays are parallel and going into the eye-piece section of the lensmeter. Thus, the distance lens is being measured under the same circumstances as when it is being worn.[3] When being worn, parallel rays enter the lens from the front. (Light paths are reversible.) The focal length is referenced as the distance from the back side of the lens. Therefore, the power being measured is called the *back vertex power*.

Although a distance lens is designed to take incoming parallel rays of light and bring them to a focus, a reading addition located on the front surface must take diverging rays of light coming from a near object and change them so they appear to be coming from farther away. In Figure 6.12, diverging light from an object at the focal length of the near segment is seen to be changed to parallel rays when going out the back side of the segment. This is easier to understand when shown together with a distance lens of zero power as shown in Figure 6.13. The person wearing this bifocal lens will not have to focus for a near object viewed through the segment of the lens.

From the previous figure, it is evident how a near (reading) addition is really just a small plus lens that is "added to" the distance lens. To tell if this plus lens segment is focusing the light as intended, we find the focal point by turning the lens around in the lensmeter. This allows the illuminated target to be optically placed at the focal point and referenced from the front surface of the lens. We are now measuring front vertex power.

Combining both distance and near lenses together when the distance lens has plus or minus power gives the situation shown in Figure 6.14. The near addition takes light from a near object and refracts the rays so that optically the rays from the near object resemble light rays coming from a more distant object. Now the distance lens is able to bring the light to a focus to meet the refractive demands of the nearsighted or farsighted presbyope.

Measuring a Front Surface Near Addition When Lens Powers Are Low

It should be noted that when distance and add powers are both low, there will be little difference between add powers found using either front or back vertex powers. For this reason, many use the easier method of measuring adds with back vertex powers instead of turning the glasses around, even when the add is on the front of the lens. As soon as distance or near powers increase, however, front-surface multifocal adds measured with back vertex powers will give wrong results. It should be noted that, until the operator is very experienced, it is advisable to turn the glasses around every time.

Measuring Add Power When the Add Is on the Back Surface of the Lens

Although most segmented multifocal lenses have the near addition on the front of the lens, there are a few segmented multifocal lenses with the segment on the back. However, with the advent of digital surfacing, things began to change. Digital surfacing allows complex surfaces to be created in the optical laboratory in a very individualized manner. When an optical laboratory has the needed equipment, complex progressive addition lens surfaces can now be placed on the front or the back of the lens—or even on both the front and the back. So when verifying a back-surface progressive addition lens (or back-surface segmented multifocal lens), the near addition power is found by taking the difference between distance and near back vertex powers. In other words, the glasses do not have to be turned around. Figure 6.15 shows the optics of a back-surface segmented multifocal lens with a plano powered distance lens. Figure 6.16 shows a plus-powered back-surface segmented multifocal lens. Both are measured in the normal way, using back vertex powers. Remember that the lensmeter operator is on the left. Light rays are reversible and are really traveling from right to left when being viewed through the lensmeter. The operator adjusts the lensmeter until the image of the illuminated target in the lensmeter clears. This occurs when the light rays traveling into the eye of the operator are parallel, first for the distance portion and then readjusted for the near portion. The dioptric difference shown between the two readings will be the add power.

Some progressive addition lenses may have the near addition power split between the front and back surfaces. When this is the case, the lens manufacturer is to specify whether the add power is to be measured using front or back vertex powers.

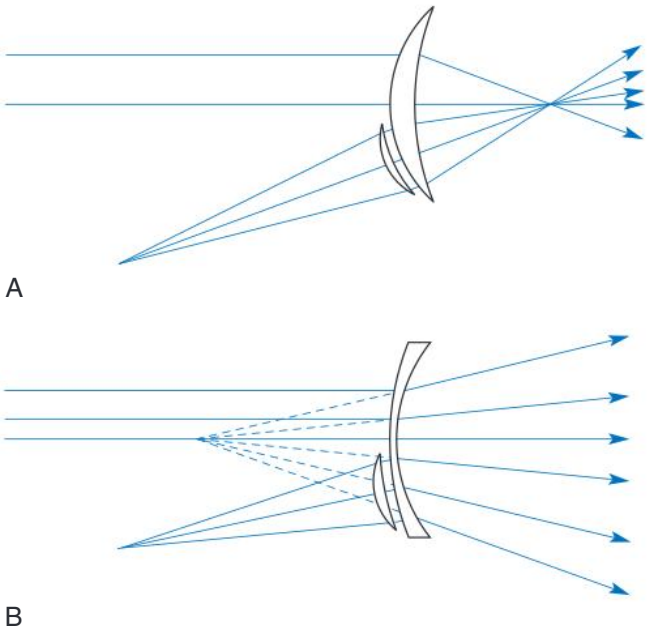

Figure 6.14 The function of a near addition is to take light from a near object and reduce the divergence of the rays. For both a plus-powered distance lens **(A)** and a minus-powered distance lens **(B),** a near add has the ability to convert diverging light from the near add focal point so that it enters the distance lens parallel. When the near addition power for front-surface multifocal lenses like these are measured in the lensmeter they are turned around. Front vertex distance and near powers are compared.

Identifying Multifocal Segment Style and Size

When ordering a replacement pair or second pair of glasses from an existing pair, it is important to identify the multifocal type. Multifocals are identified by segment style. The most commonly used visible segment styles are flat-top (sometimes called "D" segs), curve-top, and round segs. (For a more complete listing of visible multifocal lens styles, see Chapter 19, *Segmented Multifocal Lenses*. For progressive addition lenses, see Chapter 20, *Progressive Addition Lenses*.)

Measuring Segment Size

Once segment style is identified, segment size must be found. Segment size is measured across the widest portion of the segment—*not* the top

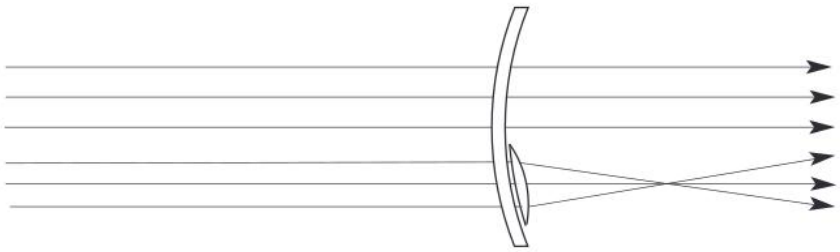

Figure 6.15 For lenses with multifocal segments on the back surface, the lensmeter would be on the right and the operator would be on the left. Light rays are reversible, so think of them as going out of the lensmeter from right to left. The lensmeter is adjusted until the rays of light are parallel when viewed. So we are comparing back vertex distance and back vertex near powers.

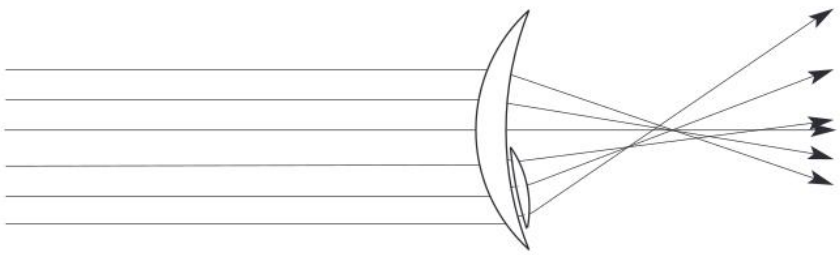

Figure 6.16 As in Figure 6.15, the lensmeter is on the right, and the operator is on the left. Since light rays are reversible, light goes from right to left and into the operator's eye. First, the back vertex distance power is read, and then the back vertex near power is read. The difference in the two readings is the add power.

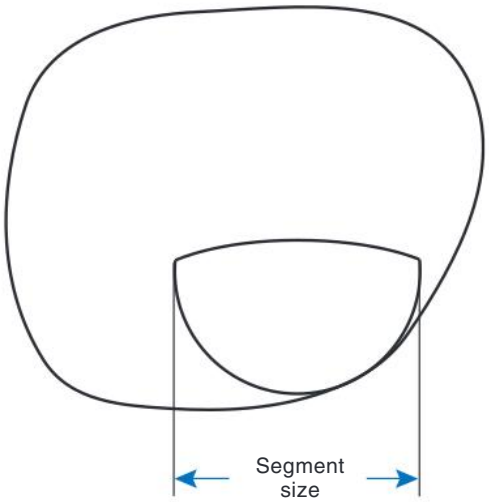

Figure 6.17 The width of a bifocal or trifocal segment is measured at the widest part of the segment. (The widest part is not always at the corner of the segment as shown here. Flat-top segments will be wider below the level of the corner of the segment.)

of the segment (Figures 6.17 and 6.18). This measure is based on the original width of the segment before the lens has been edged. So even if part of the segment has been removed during the edging process, the width is measured as if all of the segment was still there.

Trifocal sizes are identified by two numbers. The first number is the vertical size of the trifocal section in millimeters. The second number is the widest horizontal measure of the multifocal segment.

Measuring Segment Height

To measure and duplicate the segment height of an existing prescription, first the old segment height for the existing prescription is measured. If the frame will remain the same, so will the old segment height. If a different style frame is to be used, then the location of the old segment line *as it appears on the wearer* must be duplicated.

For record keeping purposes, the segment height of the existing prescription must be measured. Segment height is the vertical distance from the lowest part of the lens bevel to the top of the bifocal or trifocal segment line. (This is explained in Chapter 5 and is illustrated in Figure 5.14.)

The wearer should be asked if he or she is satisfied with the segment height of the old glasses. If so, the dispenser follows the procedures explained in Chapter 5 in the section on *Comparison With Old Lenses.* (For duplicating an old segment height in a new pair of glasses, see Figure 5.24.)

If the wearer is not satisfied or if the dispenser judges the old height to be inappropriate, a new segment height should be determined. How this is done is also explained in Chapter 5 in the section, *Measuring for Multifocal Heights.*

Identifying Base Curve

When the segment of a multifocal lens is on the front surface of the lens, the front curve is called the base curve. If an individual has more than one pair of glasses of the same power and index of refraction, it is advisable to use the same base curve for each pair of glasses. This is more critical for multifocal lenses than for finished single-vision lenses since multifocal base curves change in bigger steps. Changing the base curve may affect the way objects appear to the wearer. Straight lines may seem curved, objects may seem larger or smaller than they actually are, and the ground looks to be closer or farther away. Wearers usually adapt to normal base curve changes when lens powers change, but when base curves change and lens powers do not, switching back and forth between two pair of glasses is more difficult.

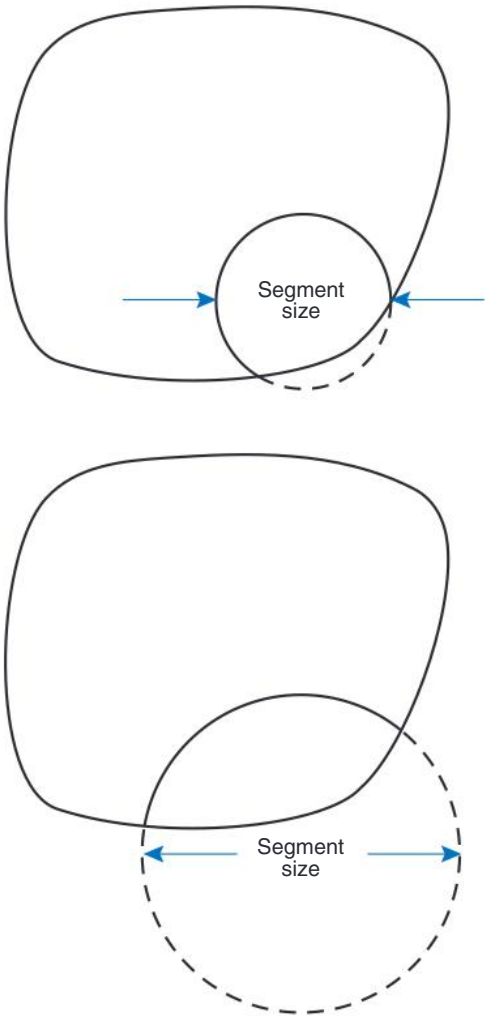

Figure 6.18 The width of a round segment is determined by its diameter. This remains true even if most of the segment has been edged away, making a physical measurement impossible. In such cases, the size of the segment is determined by estimating the location of segment borders.

Base curves are measured using a lens clock (lens measure). (For an explanation of how to use a lens clock to measure the base curve of a lens, see the section in Chapter 13 called *Finding the Refractive Power of a Lens Surface Using a Lens Clock.*)

Lens Thickness

The ANSI Z80.1 standard for acceptability, when having ordered a lens of a specific thickness, is ±0.3 mm. When specifying lens thickness, ANSI Z80.1 defines this location as being measured at the prism reference point (PRP). When there is no prescribed prism, this location will be at the OC of the lens. However, keep in mind that for minus lenses with prescribed prism, the OC is no longer at the PRP. The minimum thickness will be found at the OC, which will have less thickness than the thickness found at the PRP. This should be kept in mind if, from a safety standpoint, it is important to end up with a specific minimum thickness. (Note: The PRP may be considered a synonym for the major reference point (MRP.)

Identifying Lens Material

When examining an existing prescription for replacement purposes, when possible it is advisable to identify the lens material in the existing prescription. So how might this be done?

It is simple enough to tell the difference between glass and plastic. Lightly tapping the lens with a metallic object, such as a ring, will result in a characteristically different sound and feel. In addition to being heavier, glass also tends to feel colder to the touch than plastic.

Plastic materials are not as easy to differentiate one from another. When a polycarbonate lens is dropped on a surface with its backside down, some compare the sound to that of a poker chip. But a lens already in a frame should not be removed just to perform this procedure!

Another hint as to lens material can be gained by checking lens thickness. Polycarbonate and higher index plastics are often made thinner than regular plastic lenses of equal powers. Lens thicknesses are measured with lens calipers.

Table 6.1 has some "center thickness clues" for determining what type of material might have been used to make minus lenses of certain thicknesses. Center thickness is measured at the location of the lens PRP as shown in Figure 6.19.

Suppose a dispenser uses regular CR-39 material to replace a pair of glasses that had been made in a safer material, such as polycarbonate. Without active wearer involvement and documentation in the record, this decision could spell disaster. And since people do not always remember what material they have been wearing, their answer cannot be depended upon. In short, *the dispenser should treat the choice of lens materials as if the individual is getting glasses for the first time.* The most important point is this. *Whenever new glasses are made, the wearer must be advised of safety factors related to the different available lens materials.*

Identifying Other Lens Properties

If the current glasses are photochromic, antireflection coated, or have a tint, these characteristics should be identified and recorded. These options should be reconsidered for the new glasses as well. It should not be assumed that the wearer wants the same lens characteristics as he or she had before. (For information on tinted and antireflection coated lenses, see Chapter 22.)

TABLE 6.1 Lens Material Possibilities Based on Minus Lens Center Thickness

If Minus Lens Center Thickness Is:	Possible Material or Function Is:
<1.0 mm	Foreign-origin glass lenses (Glass lenses purchased outside the United States may not have the same impact resistance requirements and may be exceptionally thin.)
=1.0 mm or between 1.0 and 2.0 mm	Polycarbonate, Trivex, and some high-index plastics
≈1.5 mm	If glass, the lens may be made from certain Corning materials, such as "Thin & Dark" or "Corning Clear 16" glass If plastic, some high-index plastics
1.9 to 2.2 mm	CR-39 plastic
≈2.2 mm	Glass
>3.0 mm	"Non-Impact Rated" safety lenses made from any material (Note: A thick lens is not a safety lens unless it has been marked on the surface as a safety lens with the manufacturer's identifying mark.)

Note: It is not possible to identify a lens material based solely on lens thickness.

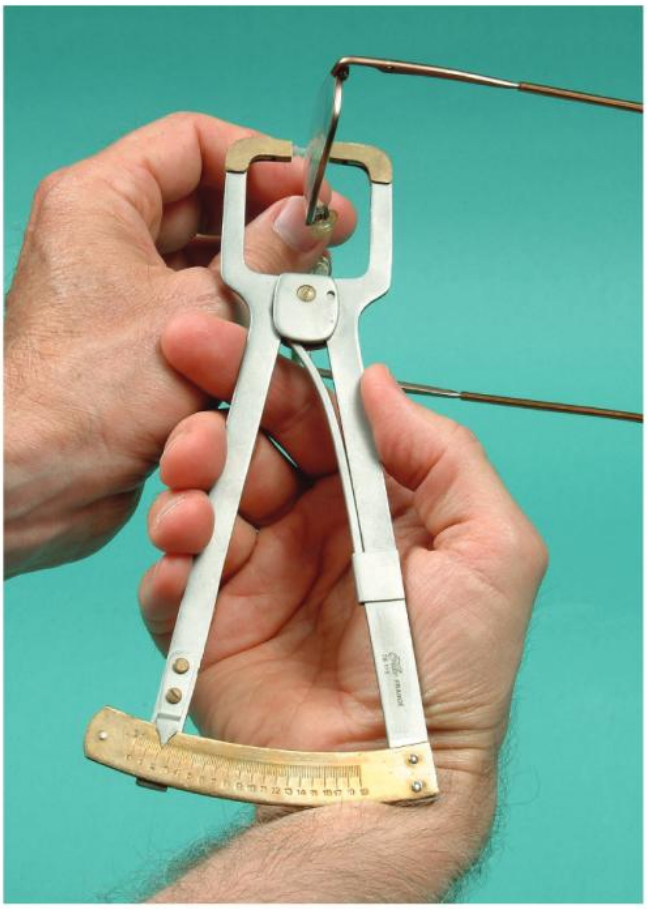

Figure 6.19 In preparation for measuring lens thickness, the lens is spotted using the lensmeter. The American National Standards Institute Z80.1 standard specifies this point as being the prism reference point (PRP). (The PRP is that point on the lens where the prism is correct for the prescription. When no prism is prescribed, this is the optical center.) The thickness of the lens may be measured with calipers as shown in this photo. Note: For minus lenses with prescribed prism, the PRP will not be the thinnest point on the lens.

What to Keep in Mind When Ordering One Lens Instead of Two

Occasionally, it becomes necessary to order one lens instead of two. This occurs when only one lens power changes from the previous examination or when one lens is damaged or broken.

When a single-vision lens is being replaced, the MRP height of the remaining lens in the prescription should be measured. The MRP height of the new lens should match that of the remaining partner lens.

When only one lens is replaced in multifocal lenses, the lens should be ordered so that the two segment heights match. This is true unless there is a measured seg height difference between the wearer's left and right eyes.

It is also important that the MRP height of the lens that is *not* being replaced be measured. This is because many optical laboratories do not place the MRP on the 180-degree midline for multifocal lenses with a

segment that is set high in the frame. This means that in order for the new lens to match the old lens, *both* MRP and seg heights should be specified. This is true even if MRP height was never specified in the original order (Figure 6.20).

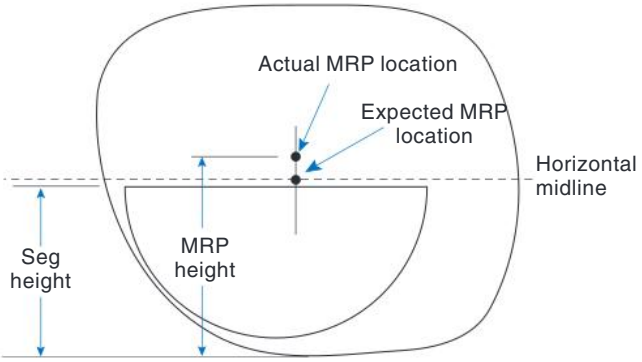

Figure 6.20 When a laboratory receives no specific instructions for major reference point (*MRP*) height, the MRP is normally placed at midlevel (on the horizontal midline). However, when the segment (*seg*) height is specified at a level that approaches or goes above this horizontal midline, many laboratories routinely place the MRP a given distance above the seg line. Common variations may be from 3 to 5 mm above the seg line. Therefore, when replacing only one lens of a multifocal prescription, the dispenser should either send the old glasses to the laboratory, or tell the laboratory the segment height *and* the MRP height for the new lens. This way the new lens will match the old lens. Failure to specify MRP height when ordering one lens only may result in unwanted vertical prism in the finished pair of glasses. (Obviously, the best way to avoid unwanted vertical prism is to send the old glasses to the lab. If the prescription is returned with vertical prism, there will not be a question about whose mistake it was.)

In some countries, a lens manufacturer may place the MRP on their bifocal lenses at a standard distance above the segment line, regardless of segment height. With increasing globalization, this may occur in some lenses sold in the United States. With this in mind, ANSI Z80.1-2020 *Prescription Ophthalmic Lenses–Recommendations* defines the term as being the *distance reference point,* or *DRP*. (DRP is commonly used with progressive addition lenses but is not often used for segmented multifocals.) The DRP is defined as "That point on a lens as specified by the manufacturer at which the distance sphere power, cylinder power and axis shall be measured."[2] Therefore, if a certain lens manufacturer always places the MRP 5 mm above the bifocal segment, then for this manufacturer the distance power would be measured at that point.

ORDERING LENSES ONLY

Ordering "Lenses Only" Using a Remote Frame Tracer

Sometimes a wearer wants new lenses for an old frame but does not have a spare pair of glasses. When the order cannot immediately be done in-house and the wearer must keep the frame, the order to the laboratory is for "lenses only." The danger in ordering "lenses only" and just specifying frame name and size is that the lenses can easily be too large or too small. The error is only evident when the wearer returns, and the dispenser attempts to insert the off-sized lens pair into the old frame. In this situation the method of choice is to remove the lenses from the frame and use a remote frame shape tracer that is connected to the computer in the optical laboratory. With a frame tracer, a stylus can trace the inside bevel of the eyewire. Both shape and size are electronically sent directly to the laboratory (Figure 6.21). In the laboratory this frame information is downloaded into the laboratory

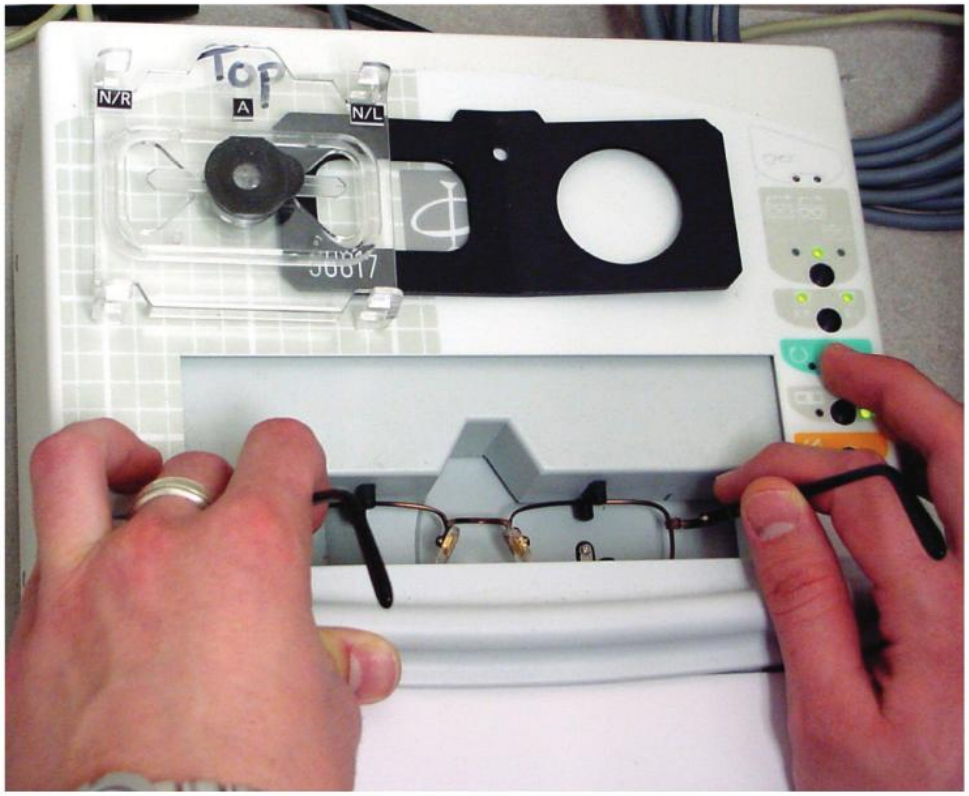

Figure 6.21 A frame tracer uses a stylus to trace the inside bevel of the frame, recording the shape. This shape is then sent to the optical laboratory and downloaded into their lens edger so that the lenses may be edged to exactly fit the measured frame. Optical laboratories use this same system to find the shape of a frame.

computer. The lenses are cut exactly to the traced shape and size. Assuming that the frame did not distort during tracing and the tracer is correctly calibrated, after the lenses are returned from the lab, the new lenses should fit into the old frame.

VERIFICATION

Verifying Lens Powers and Determining Error Tolerances

Lens power is verified using the lensmeter, and in the United States tolerances for ophthalmic lens prescriptions are set by ANSI. ANSI is a nongovernmental agency made up of representative segments of industry. The specific standard for prescription lenses is identified by the number Z80.1 and is titled *American National Standard for Ophthalmics—Prescription Ophthalmic Lenses—Recommendations.* Note: For ease of reference, the main points of this standard are summarized in Appendix A in the back of the book.

Each aspect of a spectacle lens prescription has a small range of tolerance within which that variable of the eyeglass prescription can fall and still be considered as passing. It must be recognized that it is a difficult task to fabricate a prescription that meets ANSI standards in all variables simultaneously. The writers state the following at the very beginning of the standard: "The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether he has approved the standards or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standards."[2] This is not meant to condone sloppy workmanship. Rather, it places the responsibility for determining if the finished eyewear product successfully meets the intended needs of the wearer on the eye care professional.

Tolerance for Error in Sphere Power and Cylinder Axis

The technique for using a lensmeter to measure a lens of unknown power was explained earlier in this chapter. Verifying a lens of known power with the lensmeter is much the same, but easier.

After focusing the eyepiece, the lens with the strongest power in the 90-degree meridian is placed in the lensmeter. If the lenses have similar powers and there is also prescribed prism in the prescription, then choose the lens with the most vertical prism and start with that lens.[2]

The power wheel of the lensmeter is preset for the expected sphere power, and the axis wheel is preset for the expected axis. If either of these two values is incorrect, the lensmeter's illuminated target will blur.

With the sphere power and axis preset, center the lensmeter target on the reticle. If the mires are unclear, focus the power wheel or axis wheel and note what the sphere power and cylinder axis read compared with what was ordered. (CAUTION: When presetting the axis, if the axis of the lens being verified is off by 90 degrees, it is very easy to mistakenly think that the axis is correct, when it isn't.)

Sphere power tolerances. How far away from the expected value can the sphere power of the prescription be and still be considered within tolerance?

Since a prescription may be written in either plus or minus cylinder form, the ANSI Committee needed to specify which form of prescription writing was being specified when defining sphere power tolerances. They have chosen to use the minus cylinder form of prescription writing.

For lenses up to and including a sphere value of ±6.50 D, the allowable error tolerance is ±0.13 D. For powers higher than this, the allowable error tolerance increases to ±2% of the sphere power. In other words, if a lens has a sphere power of +10.00 D, then the tolerance is:

$$10.00 \times 0.02 = \pm 0.20\,\text{D}$$

This means that a measured sphere power that falls with the range of between +9.80 and +10.20 D is acceptable according to ANSI standards.

The power standards just listed apply to single-vision and segmented multifocal lenses. They also apply to certain categories of variable focus (power variation) lenses that may include degressive or assistive lenses when these lenses have only a single reference point. It should be assumed that further standards applicable to single-vision lenses will also apply to these lenses. (See either the Glossary or Chapter 20 on *Progressive Addition Lenses* for a description of degressive and assistive lenses.)

Sphere power tolerances for progressive addition lenses. When a variable focus lens has more than one reference point (such as distance and near reference points), ANSI tolerances are slightly more lenient. Progressive addition lenses would fall into this category, as well as degressive or assistive lenses. For these lenses, the sphere power tolerance is ±0.16 D for powers up to and including ±8.00 D sph. Above ±8.00 D, the tolerance is still ±2% of the sphere power.

Cylinder axis tolerances. Cylinder axis error tolerances vary, depending on the strength of the cylinder power. For cylinder power values of less than 0.12 D, there is no defined tolerance for axis. For small cylinders (≥0.12 and ≤ 0.25 D), the axis can deviate up to 14 degrees in either direction. If the cylinder power is equal to 1.75 D or greater, however, the tolerance drops to ±2 degrees. An easy way to visualize axis tolerances is to think of a cross with the 0.25-D cylinder on the bottom and the 1.75-D cylinder on the top. This is shown in Figure 6.22.

Cylinder Power Verification and Error Tolerance

Cylinder power verification is done by finding the difference between the sphere power reading (where the narrowly spaced sphere lines focus) and the power wheel reading where the three broadly spaced cylinder lines focus. The ANSI standard cylinder power tolerances vary depending on the strength of the cylinder. For cylinder with a power of 2.00 D or less, this tolerance is ±0.13 D. For cylinders from 2.25 through 4.50 D, tolerance is ±0.15 D. Above these powers, the tolerance is ±4% of the cylinder power. When using a standard lensmeter,

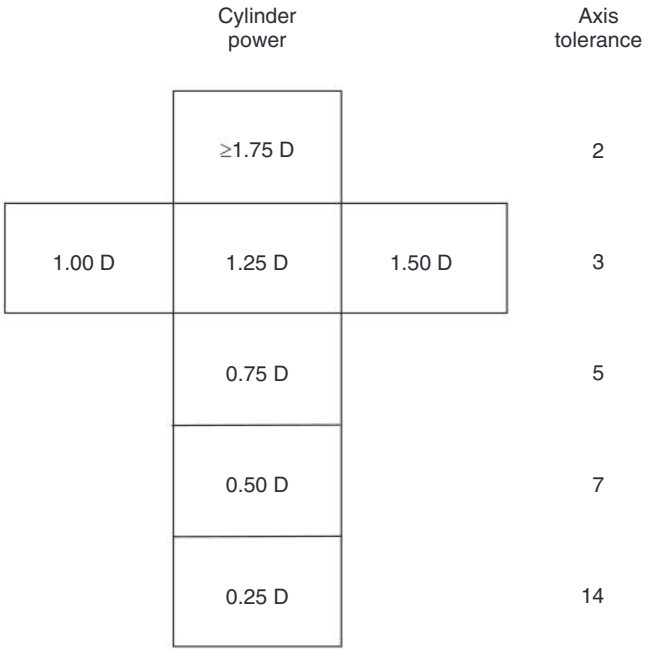

Figure 6.22 Drawing an axis tolerance cross is a simple way to remember the cylinder axis tolerances for each cylinder power.

this means the cylinder power tolerance is close to 1/8 diopter. These tolerances are slightly greater for progressive addition lenses. Exact tolerances are listed in Appendix A.

Cylinder power tolerances for progressive addition lenses. Like for spheres, cylinder power tolerances for progressive addition lenses are also somewhat more lenient. These tolerances are found in the back of the book in Appendix A, Table A.2.

Checking for Unwanted Vertical Prism

There are two methods for checking for unwanted vertical prism. The first is the more traditional method. It does not use the refractive power of the lens as part of the decision-making process. The second method uses a cut-off power to help in making the decision, simplifying the process some.

The traditional method for vertical prism tolerances. Which lens do I start with?

1. Start with the lens that has the highest power in the 90-degree meridian.
2. If the powers in the 90-degree meridian are equal and there is prescribed prism, start with the lens with the higher amount of prism in the vertical meridian.
3. If both 90-degree powers and vertical prism (if any) are equal, then by convention, start with the right lens.

After the sphere, cylinder, and axis for the first lens have been verified, spot the lens and slide the spectacles across the lensmeter table to measure the second lens. When the second lens power has been verified, spot the OC of this second lens.

If the second lens will not center but shows the illuminated target above or below the intersection of the eyepiece crosshairs, the lens is showing unwanted vertical prism. Prism amount is indicated by the numbered concentric circles on the reticle mires (or screen in some lensmeters). With the illuminated target centered exactly above or below the middle of the crosshairs, read the amount of vertical prism present. If the amount is 0.33 Δ or less, the prescription is within ANSI tolerances for vertical prism. If it is greater than 0.33 Δ, the dispenser must double-check to be sure that the lens pair has too much vertical prism.

To make this additional check, be certain the lens is centered horizontally, even though the target is off vertically. When it is horizontally centered, spot the lens. Next, move the lensmeter table up or down until the target centers vertically. Spot the lens a second time. Remove the spectacles from the lensmeter, and measure the vertical distance between these two spots. This is shown in Figure 6.23. If the vertical difference between these two dots is greater than 1 mm, the lens pair is out of tolerance for vertical prism.

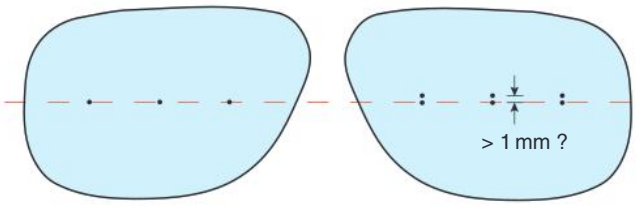

Figure 6.23 This left lens has been spotted twice: once at the actual optical center and once where the optical center should be located. Does the vertical difference between the place where the optical center should be and the place where it is really located exceed 1 mm? If it does and the amount read on the lensmeter is also above 0.33 Δ, then the lens pair will be out of tolerance for vertical prism.

It should be noted that *both* criteria must fail for the lens pair to fail. If the amount of vertical prism exceeds 0.33 Δ, but the vertical difference is less than 1 mm, the lens pair passes. If the vertical difference is greater than 1 mm but the amount of vertical prism is less than 0.33 Δ, the lens pair passes. The lens pair only fails when the vertical prism is greater than 0.33 Δ *and* the vertical difference exceeds 1 mm.

A simplified, power-based method for vertical prism tolerances. ANSI Z80 standards include a power-based method for determining whether unwanted vertical prism is within acceptable standards. The same basic procedure is followed as was explained in the preceding section. The result is the same as the traditional method explained above. Here is how it works.

If the power in the vertical meridian of the lens is low (from zero to ±3.375 D), then the only thing to worry about is whether the amount of unwanted vertical prism is above ⅓ prism diopter. If it is above this amount, the prescription is not within allowable tolerances.

If the power in the vertical meridian of the lens is high (above ±3.375 D), the amount of vertical prism is not an issue. The only thing to be concerned with is how far the OCs are away from each other vertically. If they are more than 1 mm apart, then the prescription is out of tolerance. These criteria are summarized in Table 6.2.

Here is the specific procedure for carrying out the power-based method of checking for unwanted vertical prism.

1. Verify the sphere, cylinder, and axis for the first lens.
2. Spot the first lens and slide the spectacles across the lensmeter table. Verify and spot the OC of the second lens.
3. If the second lens will not center, move the lens sideways until the illuminated target centers exactly above or below the middle of the crosshairs. Read the amount of vertical prism present and spot the lens.
   a. If the prism amount is 0.33 Δ or less, the prescription is within ANSI tolerances for vertical prism and passes.
   b. If the prism amount is greater than 0.33 Δ and the power in the vertical meridian is 3.25 D or *less*, the prescription fails.
4. If the prism amount is greater than 0.33 Δ and the power in the vertical meridian is 3.50 D or *more*, the lens pair *may* still pass. To find out, continue with the following steps.
5. Move the lensmeter table up or down until the target centers vertically. Spot the lens a second time.
6. Remove the spectacles from the lensmeter, and measure the vertical distance between these two spots as was shown in Figure 6.23.
   a. If the vertical difference between these two dots is 1 mm or less, the prescription passes.
   b. If the vertical distance between these two spots is greater than 1 mm, the prescription fails.

Checking for Unwanted Horizontal Prism

Here is how to start out. By now the spectacle lens pair has both lenses spotted. To check for unwanted horizontal prism, start out like this.

1. Measure the horizontal distance between the center lensmeter dots on the two lenses as shown in Figure 6.24, *A*.

TABLE 6.2 Allowable Unwanted Vertical Prism Based on Lens Power

If the Power in the Vertical Meridian Is	The Allowable Imbalance Tolerance Is
±3.25 D or less	0.33 Δ or less of vertical prism
±3.50 D or more	1.0 mm or less of vertical difference in major reference point locations

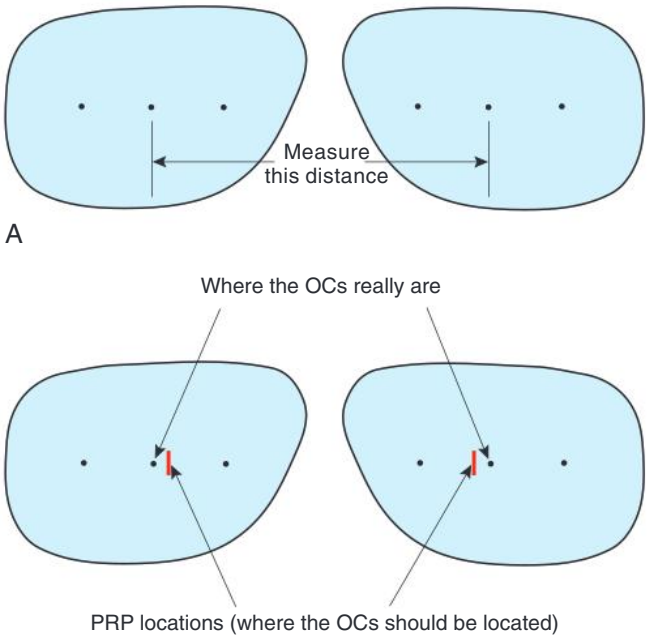

Figure 6.24 **A,** Measure the horizontal distance between the two center lensmeter dots (the locations of the lens optical centers [*OCs*]). **B,** Now compare this distance to the distance of where the wearer's eyes will be located, in other words, where the ordered distance interpupillary distance (PD) locations should be found. If the difference is less than 2.5 mm, horizontal prism is within tolerance. If the difference is greater than 2.5 mm *and* the lens pair shows greater than 0.67 Δ horizontal prism, the prescription is out of tolerance. When there is prescribed prism in the prescription, think prism reference point (*PRP*) locations. The PRP locations are where the prescribed prism is correct. The difference between the distance between the PRP locations and the wearer's actual distance PD should be less than 2.5 mm.

2. Compare this distance to the PD that was ordered.
   a. If the difference between the ordered PD and the measured PD is 2.5 mm or less, the prescription passes.
   b. If the difference is greater than 2.5 mm, the prescription *might* fail. We will not know this, however, until we check for horizontal prism tolerance limits.

There are two methods to finish out checking for horizontal prism tolerance limits if the OC distances are more than 2.5 mm away from the wearer's PD. The first method is easier to understand but harder to do. The second is harder to understand initially but, in the end, is easier to do. The second method is preferred and is recommended by ANSI.

Method 1: Spotting the location where the optical centers should have been. The first method requires spotting the PRP location. The PRP is where the OCs should have been. (If there is prescribed prism, it is located where the correct amount of prescribed prism should have been.) Here are the steps to follow:

1. Measure from the center of the bridge to find where the right PRP should be located. Do this by using the right monocular PD (or half binocular PD). It is measured from the center of the bridge. Mark this PRP location on the lens by dotting or drawing a vertical line using a lens marking pen.
2. Do the same for the left PRP using the monocular (or half binocular) PD (see Figure 6.24, *B*).
3. Next, center this new PRP mark on the right lens in front of the lensmeter stop.
4. Read the amount of unwanted horizontal prism from the lensmeter and remember it.
5. Do the same for the left eye.
6. Add both left and right horizontal prism amounts together.
   a. If these two amounts are 2/3 prism diopter or greater, the prescription is out of tolerance.
   b. If they are less than 2/3 prism diopter, the prescription is within horizontal prism tolerance.

Method 2: Determining if the wearer's PD is within the 2/3 prism diopter limit. It has already been determined that the OCs of the lenses are more than 2.5 mm away from where the wearer's PD should be. There is one dot on each lens showing the location of the OC (or PRP) of each lens. Note: If there is prescribed prism, the dots should be located where the amount of prescribed prism is correct. These are the locations of the PRPs.

To check for horizontal prism tolerance limits, put the spectacles back in the lensmeter and do the following:

1. For the first lens, place the center lensmeter dot in front of the lensmeter stop. (The stop is the aperture part of the lensmeter against which the back surface of the lens rests.)

2a. If the distance between the two dots on the lenses is wider than the wearer's PD, slide the lens outward until the prism amount seen through the lensmeter increases to 1/3 prism diopter. At this point, stop and spot the lens. (It may help to think of it this way: If the OCs are too far outward compared to the wearer's PD, move the lens outward.)

2b. If the distance between the two dots on the lenses is narrower than the wearer's PD, slide the lens inward until the prism amount seen through the lensmeter increases to 1/3 prism diopter. At this point, stop and spot the lens. (Again, it may help to think of it this way: If the OC's are too far inward compared to the wearer's PD, move the lens inward.)

3. Repeat this procedure for the second lens.
4. Measure the distance between the two sets of lensmeter dots on the two lenses (outside dot to outside dot and inside dot to inside dot). If the size of the wearer's PD is between these two measured sets of points, the glasses pass horizontal prism standards. If the size of the PD is outside of these two measured sets of points, the glasses fail horizontal prism standards.

A power-based method for helping to determine horizontal prism tolerances. As with vertical prism tolerances, there is also a power-based method for determining whether unwanted horizontal prism is within acceptable standards. Again, the end results are the same as in the previously explained methods for determining horizontal prism. This is the procedure.

If the power in the horizontal meridian of the lens is low (from zero to ±2.75 D), then the only thing to worry about is whether the amount of unwanted horizontal prism is above ⅔ prism diopter. If it is above 0.67 Δ (i.e., 2/3 Δ), the prescription is not within allowable tolerances.

If the power in the horizontal meridian of the lens is high (above ±2.75 D), the only thing to be concerned with is how far the OCs are away from each other horizontally. This will tell us how far the PD is off. If the separation of the OCs is more than 2.5 mm away from the wearer's PD, then the prescription is out of tolerance for unwanted horizontal prism. These criteria are summarized in Table 6.3.

Example 6.3

Suppose a prescription has a distance power of −0.75 D for both right and left lenses. The wearer's distance PD is 58 mm. We want to verify the prescription for horizontal prism. When the lens optical centers (OCs) are spotted, the distance between these two centers is 63 mm. Is the prescription out of tolerance for unwanted horizontal prism?

Solution

Because the OCs for this prescription are 63 mm apart when they should be 58 mm apart, the spectacles clearly exceed the 2.5-mm tolerance criterion for horizontal prism. The 2.5-mm criterion would only allow the OC distance to vary from 55.5 to 60.5 mm. But this alone does not indicate that the prescription fails American National Standards Institute (ANSI) standards. The lens pair has not yet been checked for 0.67 Δ horizontal prism tolerance. (Since the power of the prescription is less than 2.75 D, the amount of prism is critical.) To check for horizontal prism tolerance, place the right lens in the lensmeter with the OC at the lensmeter stop as shown in Figure 6.25. Set the lensmeter for the correct sphere power and cylinder axis. Be certain that the target is clear.

Because the distance between the OCs is wider than the wearer's PD and this is a right lens, the glasses are moved outward (to the left). Look into the lensmeter, move the glasses to the left, and watch the amount of horizontal prism increase. Stop and spot the lens when the prismatic effect reads 0.33 Δ.

Repeat this for the left lens. Again, the lens is moved in an outward direction. But since the lens is a left lens, outward is now to the right. Move the lens until the prismatic effect reaches 0.33 Δ. Stop and spot the lens. The glasses now look like those shown in Figure 6.26.

Next measure the distance between the new lensmeter dots. This distance measures 54 mm. The OC separation distance measures 63 mm. The wearer's PD is 58 mm. This 58-mm distance falls in between 63 and 54 mm, so the prescription passes unwanted horizontal prism tolerances. This is true even though it failed the 2.5-mm criterion. To fail, it must fail both criteria. (For a summary of horizontal and vertical prism standards, see Appendix A in the back of the book.)

TABLE 6.3 Allowable Unwanted Horizontal Prism Based on Lens Power

If the Power in the Horizontal Meridian Is:	The Allowable Imbalance Tolerance Is:
From 0.00 to ±2.75 D	0.67 prism diopters
Above ±2.75 D	2.5 mm total

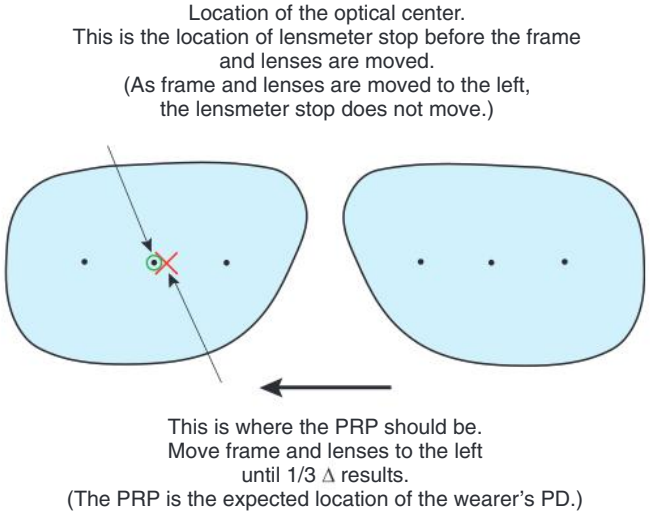
Location of the optical center.
This is the location of lensmeter stop before the frame
and lenses are moved.
(As frame and lenses are moved to the left,
the lensmeter stop does not move.)
This is where the PRP should be.
Move frame and lenses to the left
until 1/3 Δ results.
(The PRP is the expected location of the wearer's PD.)

Figure 6.25 Here is how to see if there is less than 2/3 prism diopter of unwanted horizontal prism following that described in the section *Method 2: Determining If the Wearer's PD Is Within the Two-Thirds Prism Diopter Limit*. In this example, to check for horizontal prism tolerances, we are starting with the right lens. The distance between the optical centers (63 mm) is wider than the wearer's interpupillary distance (*PD*; 58 mm), so we will move the lens outward (to the left). Keep moving the spectacles in an outward direction until the prism in the lensmeter reads 0.33 Δ. Then spot the lens (see Figure 6.26). *PRP,* Prism reference point.

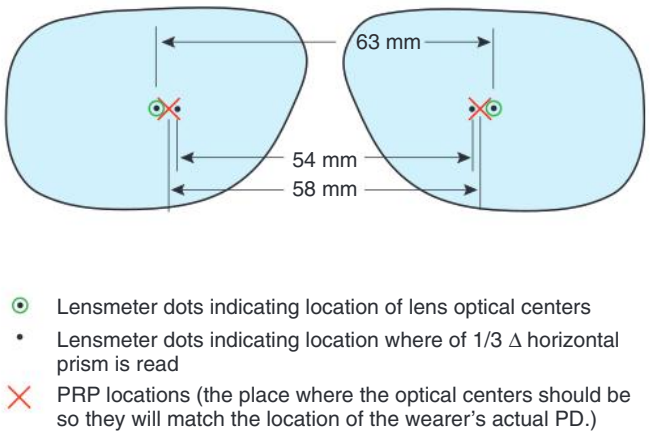
63 mm
54 mm
58 mm
Lensmeter dots indicating location of lens optical centers
Lensmeter dots indicating location where of 1/3 Δ horizontal prism is read
PRP locations (the place where the optical centers should be so they will match the location of the wearer's actual PD.)

Figure 6.26 Continuing the example, the distance between the optical centers measures as 63 mm, but the wearer's interpupillary distance (*PD*) is 58 mm. Since it was possible to move the glasses all the way to 54 mm before 0.33 Δ per lens occurred, the prescription passes. (To put things into perspective, this particular −0.75 Δ sph prescription could have the optical center separation vary anywhere from 49 to 67 mm and still not fail American National Standards Institute standards for horizontal prism. The lower the refractive power is, the farther the optical centers can be off from where they should be without reaching a total of 0.67 Δ for the pair.) In the figure, PRP refers to the prism reference point.

Verifying for Prescribed Prism

A lens that has prescribed prism is not centered the same in a lensmeter as a prescription without prism. The prismatic prescription is not centered correctly if the illuminated lensmeter target is at the intersection of the crosshairs. Centering of a prismatic prescription is correct when the illuminated target is located at the point in the lensmeter that matches the prescribed amount of prism. When this happens, the lens should be dotted at this point for verification. This is the location of the PRP.

Example 6.4

A right lens prescription reads:

$$+3.00 - 1.25 \times 135, 2.00\Delta \text{ base out}$$

How must the lens be centered before it is spotted?

Solution

To verify this prescription, the lens must be placed in the lensmeter and moved until the illuminated target is located 2 Δ units to the left (temporal) of the crosshair origin (Figure 6.27). (Target center location always corresponds to prism base direction. This is true whether the lens is plus or minus in power.)

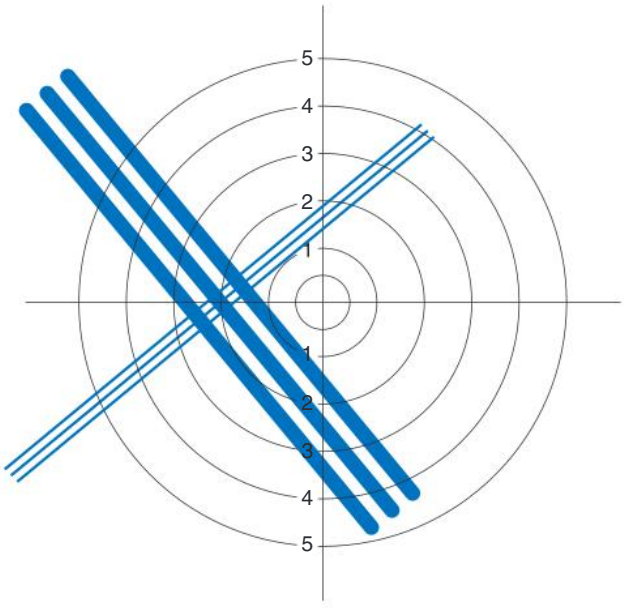

Figure 6.27 In this example, assuming the lens is a right lens, the illuminated target indicates 2.00 Δ base-out prism. (If the lens being measured were a left lens, we would read the prism as 2.00 Δ base-in prism.)

Example 6.5

Another right lens prescription reads:

$$+3.00 - 1.25 \times 135, 1.00\Delta \text{ base down}$$

How must the target be centered for this lens before it is spotted?

Solution

Everything except prism is identical to the previous prescription. Therefore, in this case, the only difference is that the illuminated target is moved until it is located directly below the crosshair origin, 1 Δ base-down, as shown in Figure 6.28.

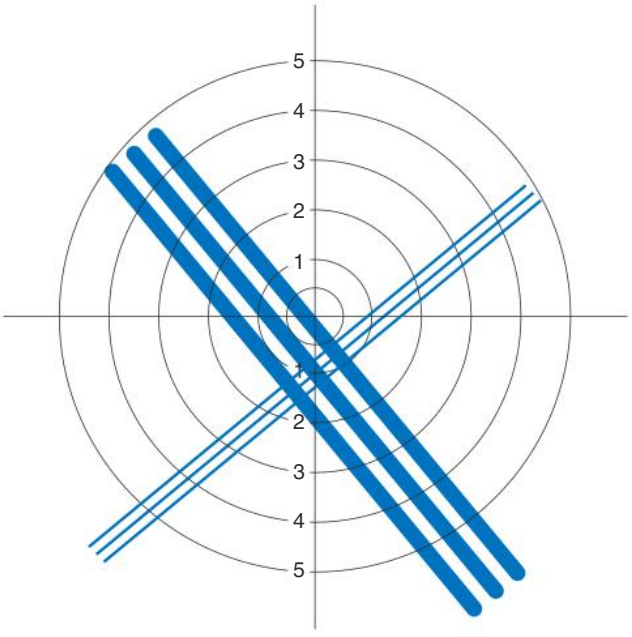

Figure 6.28 This prismatic effect reads 1 Δ base-down. This is true whether the lens is a left or a right lens because the prism base direction is vertical instead of horizontal.

Example 6.6

Suppose a right lens prescription with the same refractive power as in the previous two prescriptions calls for horizontal *and* vertical prism. Prism values ordered were 1.00 Δ base-down and 2.00 Δ base-out. How must the illuminated target be positioned for accuracy in verification?

Solution

When both horizontal and vertical prism are called for, the illuminated target must be moved both horizontally and vertically. The correct positioning is shown in Figure 6.29. (Note that the illuminated lensmeter target is not on the 2 Δ lensmeter ring. However, it is directly below the place where the 2 Δ ring crosses the horizontal line and directly to the left of where the 1 Δ ring crosses the vertical line.)

Prism Tolerances With Prescribed Prism

When a prescription includes prescribed prism, the process for determining if there is unwanted horizontal or vertical prism is very close to that previously described for prescriptions with no prescribed prism. The only difference is this. With no prescribed prism, the desired starting location of the illuminated lensmeter target is at the center of the reticle mires, indicating zero prism. Variance from zero tells us if we are in or out of tolerance. With prescribed prism, the starting point is indicated when the illuminated target is at the location on the reticle mires where that prescribed prismatic effect is correct. If, for example, there is 2.00 Δ base-down prism prescribed, the prism tolerance amount will allow a reading for vertical prism between 1.67 Δ base-down and 2.33 Δ base-down and still be acceptable.

Verifying High Amounts of Prism

When verifying high amounts of prism with the lensmeter, it is not uncommon for the prism to displace the center of the illuminated target completely off the lensmeter viewing screen. This will leave only sphere or cylinder lines in view but not both. When this happens, the prism amount is read using one of two methods, depending on the type of lensmeter. One method uses a loose, compensating prism. The other requires a prism-compensating device.

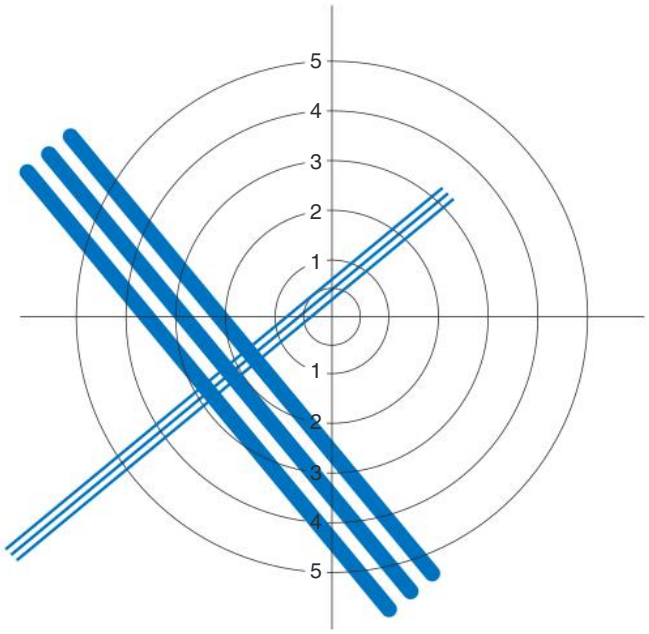

Figure 6.29 If a right lens is being verified for prescribed prism of 2.00 Δ base-out and 1.00 Δ base-down, it must be positioned as shown before the lens can be spotted.

Using loose auxiliary prisms to measure large prismatic effects. Some lensmeters, such as the B&L Reichert, come with prism lenses that are placed in a special lens-holding cell in the instrument. The prism lens is oriented with its base direction opposite to the spectacle lens' prism base direction so that the illuminated target center will be returned to the screen. The sequence of steps for finding prism is as follows:

1. An attempt to read a prescription with a high amount of prism is made, but the lensmeter's illuminated target center is displaced off the viewing screen. Once this has happened, look at the prescription and estimate prism base direction. Estimating is done by observing lens thickness differences. The thickest edge of the lens indicates the probable prism base direction.
2. Measure or look up the wearer's PD. Using a lens marking pen, dot the location of where the MRP should be for right and left lenses to match the wearer's PD. (This procedure is explained in this chapter in the section called *Method 1: Spotting the Location Where the Optical Centers Should Have Been*.)
3. Estimate the base direction and approximate amount of prism that will be necessary. (If your estimated prism amount is off, it can be adjusted later.) Without the spectacles or any other lenses in the lensmeter, put the auxiliary prism in the cell of the lensmeter so that its base direction is *opposite* to the base direction of the prism in the spectacle lens (Figure 6.30). Orient the base direction of the auxiliary prism to be either totally horizontal or totally vertical. Choose based on whether the higher prism amount is horizontal or vertical.
4. Now the auxiliary prism base direction needs to be calibrated. To do this, set the lensmeter cylinder axis at 180 degrees and the sphere power on zero. Look into the lensmeter. Slightly rotate the auxiliary prism until the center line of the illuminated lensmeter target crosses the middle of the crosshairs. This will ensure that the prism base direction is exactly zero or 180 degrees (base-in or base-out) with no vertical component. If a large amount of vertical prism is being measured, this will ensure that the base direction is 90 or 270 degrees (base-up or base-down) with no horizontal component.

Figure 6.30 An auxiliary prism is used to help verify a lens with a large amount of prism in the prescription. The prism base of the auxiliary prism is placed opposite the prism base direction we expect to find in the prescription.

5. Next, place the spectacles in the lensmeter and center the MRP of the lens being measured over the lensmeter stop. If the target does not appear, increase the amount of prism by choosing the next higher auxiliary prism. (Each time a different auxiliary prism is placed in the cell, the alignment process described in the previous step must be repeated.)
6. When the illuminated target is visible on the screen, note the prismatic amount seen in the lensmeter. To figure the total amount of prism, reverse the base direction of the auxiliary prism and add it to the prism amount shown in the lensmeter. In other words if the prism on the screen shows 1.00 Δ base-out and the auxiliary prism is 6.00 Δ base-in, change 6.00 Δ base-in to 6.00 Δ base-out and add it to 1.00 Δ base-out. The amount of prism present in the lens is 7.00 Δ base-out.

Example 6.7

A lens cannot be read in the lensmeter without the help of compensating prism. A 5 Δ base-in auxiliary prism allows the target to be seen. The illuminated target shows up at a point on the screen that measures as 4 Δ base-out and 1 Δ base-up. How much prism is there in the lens?

Solution

The 5 Δ auxiliary prism is oriented with its base opposite that of the prism in the lens. To figure the amount of prism present in the lens, change 5 Δ base-in to 5 Δ base-out. Now add the 5 Δ base-out that was neutralized by the auxiliary prism to the 4 Δ base-out and 1 Δ base-up that was viewed on the screen. This makes the total amount of prism 9 Δ base-out and 1 Δ base-up.

Using a prism-compensating device to measure large amounts of prism. Some lensmeters, such as the Marco and R.H. Burton lensmeters, come with a prism-compensating device (Figure 6.31). (This device is called a *rotary prism*, or *Risley prism*.) To find prism amount and prism axis direction using a rotary prism, begin by placing the PRP of the lens against the lensmeter's aperture. (To review, the PRP is defined as "That point on a lens as specified by the manufacturer at which the prism value of the finished lens is to be measured."[2]) The PRP will correspond to the location of the wearer's monocular PD or to one-half the wearer's binocular PD for a given pair of glasses. This is where the PRP of the lens should be.

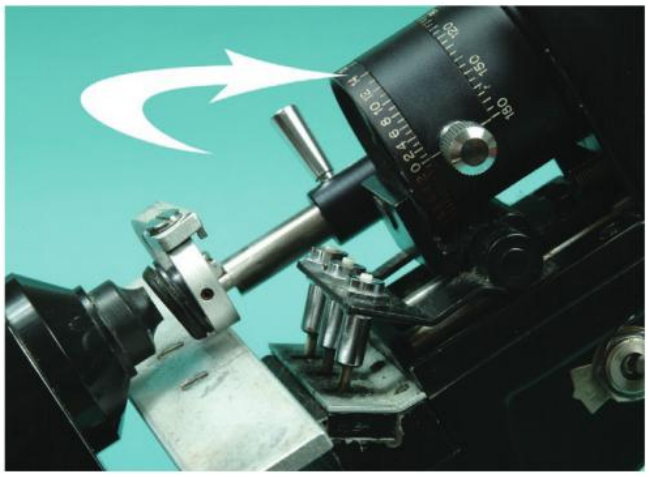

Figure 6.31 A prism-compensating device, such as the one shown here, allows a highly prismatic lens to be verified. For lensmeters with prism-compensating devices, before any lens is measured, the lensmeter should always be checked to ensure that the compensating device is zeroed out. Otherwise the lensmeter will appear to be detecting prism in a lens when there is none. (A prism-compensating device is based on the Risley prism principle. A Risley prism consists of two rotating prisms that work together to vary prism power. Prism power will be zero when the bases of the two prisms are oriented in opposite directions—apex to base. Prism power will be at a maximum when the bases are both in the same direction. For more on this topic, see the section titled *Rotary Prisms* in Chapter 15.)

Turn the power wheel to the sphere power of the prescription and the axis wheel to the correct cylinder axis. Next, move the illuminated target using the rotary prism–compensating device so that the larger prismatic component (either horizontal or vertical) allows the illuminated target center to reappear within the viewing area of the lensmeter.

(Compensating prism power is increased or decreased by turning the knob on the compensating device. Base direction of the compensating prism is changed by physically moving the knob so that it rotates around the axis of the lensmeter.)

Turn the knob of the rotary prism–compensating device to move the illuminated target onto either the horizontal or vertical crosshair on the measuring reticle. This is done by using just horizontal or just vertical prism.

By moving the illuminated target onto the vertical line of the reticle mires, the amount of horizontal prism may be read from the rotary prism–compensating device. Any vertical prism is read internally from the reticle mires. By moving the illuminated target onto the horizontal line of the reticle mires, the amount of vertical prism may be read from the rotary prism–compensating device. Any horizontal prism is read internally from the reticle mires.

In other words, leave the base direction of the rotary prism–compensating device at either 90 or 180 degrees. (Remember, the base direction for the lens may be estimated ahead of time just by looking at the thickness differences between temporal and nasal lens edges or by the thickness differences between top and bottom edges.) Read the larger prismatic component that has been neutralized from the rotary prism-compensating device. Read the smaller prismatic component directly from the reticle. (See Box 6.3 for a summary of these steps.)

An important note about the rotary prism–compensating device. When using a lensmeter, it is important to be certain that the illuminated target within the lensmeter is centered at the middle of the reticle mires. Otherwise prism readings will be inaccurate.

When using a lensmeter with an external rotary prism, it is easy to bump up against the rotary prism and accidentally turn the knob. This will introduce a small amount unintended prismatic effect into the instrument. Check the lensmeter to make certain it reads zero prism without a lens. Otherwise, all readings will show a prism amount that can be quite confusing and make prescription spectacle lenses look as if they are prismatically incorrect.

Checking for Unwanted Prism in Progressive Addition Lenses

Prism in a progressive addition lens is checked at the location of the PRP. The PRP on a progressive addition lens is defined by the manufacturer. When the lenses come back from the lab, the points of verification are visibly marked, including the PRP. (See Figure 20.6 in Chapter 20, *Progressive Addition Lenses*.) These visible marks were applied either by the manufacturer or reapplied by the optical laboratory if the markings are no longer readable after the lens has been surfaced and edged.

If these marks are gone, they may be reapplied with the help of two primary semivisible reference markings (usually small circles) on the lens. These permanent, microengraved circles are to be dotted and the dotted lens points appropriately placed on the lens manufacturer's centration chart. An example of a centration chart is seen in Figure 20.2. If there is doubt as to the accuracy of the lab-applied markings, these lab markings (usually yellow in color) may be removed and reapplied, based on the two semivisible markings. Most often the engraved markings are found on the front surface of the lens but may instead be located on the back surface of digitally surfaced (free form) lenses.

When reading prism, the PRP of the progressive lens is centered in front of the lensmeter's aperture. Tolerances for unwanted horizontal and vertical prism for progressive lenses are given in Appendix A, Table A.9. (Note: Progressive addition lenses are often made thinner by using vertical prism of equal amount and direction in both right and left lenses. This paired vertical prism is called *yoked base-down prism* since its direction is usually downward. If both

BOX 6.3 Using a Rotary Prism–Compensating Device to Read Large Amounts of Prism

1. Dot the location of the wearer's eye on the lenses using monocular interpupillary distance (PD) measurements (or 1/2 distance PDs if monocular PDs were not specified).
2. Place the marked monocular PD locations from Step 1 directly in front of the lensmeter aperture. (Use the center pin on the lensmeter's dotting mechanism to be certain that the marked reference point is exactly centered in front of the lensmeter aperture.)
3. Turn the power wheel to the sphere power of the prescription and the axis wheel to the correct cylinder axis.
4. Estimate which prism component is larger, horizontal or vertical. (To do this, look at the thickness differences between temporal and nasal lens edges and the thickness differences between top and bottom edges.)
5. Physically move the knob on the rotary prism-compensating device to position the prism base direction to 180 degrees if horizontal prism is larger or to 90 degrees if vertical prism is larger.
6. Move the internal illuminated target onto either the horizontal or vertical crosshair on the internal measuring reticle. (Turning the knob on the rotary prism-compensating device will accomplish this by increasing or decreasing prism amount.)
7. Read the larger prism component from the external rotary prism-compensating device.
8. Read the smaller prism component from the reticle scale inside the instrument.

lenses have equal amounts of base-down prism, binocular vision is not disturbed and the lens pair is within tolerance for unwanted vertical prism.)

Using an Autolensmeter to Verify Lenses

Autolensmeters come in varying degrees of sophistication. Although different instruments will vary in the protocol for operation, the basic sequence for use involves the following:

1. Select lens form and accuracy.

   The operator indicates whether the lens is to be read in plus or minus cylinder form. The level of accuracy is also indicated, since instruments will read lens power to the nearest quarter diopter, eighth of a diopter, or hundredth of a diopter. When verifying digitally surfaced lenses with prescribed powers compensated for vertex distance, lens wrap and tilt, using hundredth diopter increments can be helpful in determining whether or not the lens is within ANSI power tolerances.
2. Position the first lens.

   The lens is positioned by moving it until centered. Instead of viewing a conventional crossed-line or a corona target, the image may consist of a cross that appears on a small screen. The lens can be made to approach the center of the screen and may become bolder as it reaches the center.

   Some instruments allow the instrument to be operated with or without centering the lens. With centering, the spectacle lens is positioned with the location of the wearer's PD in front of the autolensmeter's aperture. The instrument reads both power and prismatic effect at that point. This mode is used when monocular PDs are known or when using binocular half-PDs.

   A second mode allows a reading to be taken at any position on the lens. Once the second lens reading is taken, the instrument uses the powers and prismatic effects of the two lenses at the measured locations to calculate the locations of the lens OCs. This enables the instrument to show the distance between the OCs. This distance may be compared to the wearer's PD.
3. Spot the lens.

   The lens may be spotted with the customary three lensmeter dots if it has been conventionally centered as described at the beginning of Step 2 above.
4. Position and spot the second lens.

   The next step for a single-vision lens pair is to position and spot the second lens. Some autolensmeters have an intermediate step for multifocals whereby the add is measured before the second lens is measured.
5. Print and/or read the results.

   It is worth noting that when reading a lens power, the lens should be adjusted so that, at the point of measurement, the back surface of the lens is perpendicular to the viewing axis of the instrument. In other words, at the point of measurement the back surface should not be tilted.

Advantages of the autolensmeter. An autolensmeter may have certain advantages over a manual lensmeter. These include:

- Less operator expertise is required than for manual types.
- When equipped with a printer or connected to an electronic health record, it provides a permanent record of the reading.
- Dioptric readings are possible in 0.25-, 0.12-, and 0.01-diopter increments.

  (Note: The 0.01-D increment is subject to variations in accuracy because of individual instrument circuitry. From a practical standpoint, it should not be assumed that the expected precision of the 0.01-D readout is 100% accurate. In addition, it should not be assumed that, if the instrument was checked for accuracy initially and found acceptable, it will necessarily retain that accuracy over time. Because of instrument drift, accuracy should be checked from time to time using standard lenses of known powers.)
- Results are provided in either plus or minus cylinder format, as desired.
- Some autolensmeters can determine whether unwanted prism is within ANSI prism tolerances.
- To increase accuracy, some instruments allow Abbé values for different lens materials to be entered.

Advantages of the manual lensmeter. Despite the convenience of the autolensmeter, there are some aspects of lens measurements in which the manual lensmeter has the advantage.

- The manual lensmeter allows the operator to have a visual picture of material and lens surface quality. Because the manual lensmeter operator sees the illuminated target directly, irregularities will be detectable. These aberrations or distortions are not detectable with commonly used autolensmeters but are with manual lensmeters. These irregularities include:
  - subtle changes in lens surfaces such as waves or warping.
  - internal defects in the media of the lens material.

    These are further explained in the section on *Checking for Small Surface and Media Defects*.
- A skilled operator can verify lenses quickly and accurately with a quality manual lensmeter.

Verifying Lens Segments and Surfaces

Verification of the Multifocal Segment

To verify the size and location of the multifocal segment, do the following:

1. Check segment height. ANSI Z80 tolerance is 1 mm per lens and 1 mm total difference between segment heights. (Fitting cross height tolerances for progressive addition lenses are the same as for multifocal segment heights. [See Appendix A.8.])
2. Check flat-top bifocals for tilt by placing a ruler across the tops of both segments (Figure 6.32) (ANSI Z80 tolerance is 2 degrees of tilt. This is the same tilt tolerance as for the two progressive addition lens semivisible alignment reference markings. These markings are usually small hidden circles.)
3. Measure seg width with a ruler at the widest part of the seg. (ANSI Z80 tolerance is 0.5 mm.)

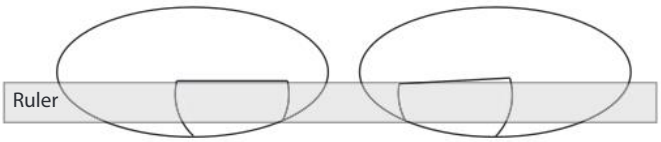

Figure 6.32 To verify whether segmented multifocal lenses are straight, place a ruler across the tops of both segments. The segments' tops must parallel the ruler. If they do not, as is the case here, one or both lenses may be rotated in the frame. If rotating the lens causes the shape of the frame to be distorted, the lens is unacceptable. If the frame does look acceptable, the lens prescription should be checked to assure that the lens was not rotated to an off-axis position. The lens pair should also be checked for unwanted vertical prism since the lens optical center might have been rotated too far upward or downward compared with the other lens. (Note: For progressive addition lenses, the semivisible circles may be located and spotted with a lens-marking pen. Horizontal alignment of these circles can also be checked with a ruler in this same manner. *American National Standards Institute Z80.1* tilt tolerances for both segmented multifocal lenses and progressive addition lenses are 2 degrees.)

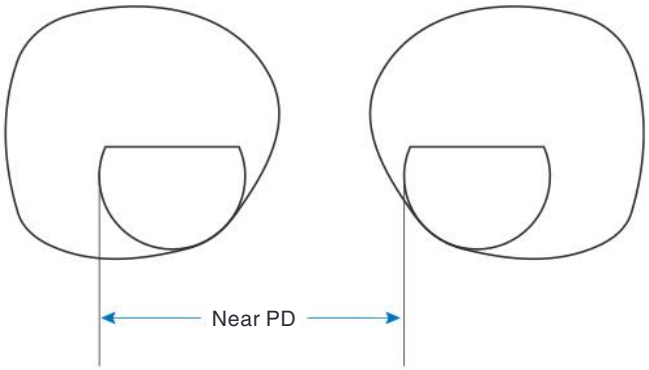

Figure 6.33 When both multifocal segments are identical, it is easier to measure near interpupillary distance (*PD*) from the left side of one segment to the left side of the other than from center to center.

4. To verify the near PD ordered, measure the distance from the left side of one seg to the left side of the other (Figure 6.33). A lens pair should be within 2.5 mm of the ordered amount to be within standards.

Checking Lens Surface Curves, Size, and Tint

Using a lens clock, check the base curve and look for the presence of warpage. (Information on the *lens clock* is found in Chapter 13 in the section titled *Measurement of Lens Curvature.*) Warpage is revealed by two different surface powers (indicating cylinder power) found on both front and back surfaces instead of on just one surface.

Check the lens size, particularly in a "lenses only" order. Be sure the tint corresponds with that ordered.

Checking for Small Surface and Media Defects

Check for internal media defects such as bubbles and striae in the lens material. A *stria* is a streak seen in a lens caused by a difference in the refractive index in the material. When seen, a stria occurs in a glass lens. The streak causes a distortion in the object viewed and is not a physical streak like a mark on or in the lens. Also inspect the surface for scratches, pits, or areas of grayness.

The surface is also inspected for waves. A *wave* is a defect in lens surface curvature, which causes a slight, irregular variation in the surface power. A wave may be seen using a manual lensmeter and may seem like an irregularity in a section of the illuminated target. It can become more apparent when the lens is moved back and forth slightly in the lensmeter. It is created during the lens surfacing process and can occur with any type of lens material. One can also check for waves by holding the lens about 12 inches from the eye and viewing either a grid or some object having a straight edge. Move the lens slowly back and forth. The straight edge should appear smooth. It should maintain its smoothness and become increasingly curved as the straight edge being viewed approaches the edge of the lens. Waves should not be confused with the larger changes that are observed in a progressive addition lens. These are intended changes in surface power that are regular and predictable.

If there is a localized distortion present (Figure 6.34), mark the area, and view it through the lensmeter. If the area distorts the lensmeter target, the defect makes the lens unacceptable. However, if the defect is outside of a 30-mm-diameter circle that is centered on the MRP or if the defect is within 6 mm of the lens edge, the lens may be considered acceptable. In fact, the same applies to any small isolated material or surface defect and not just waves. If small, isolated defects are outside of the 30-mm-diameter circle or within 6 mm of the lens edge, they are acceptable.

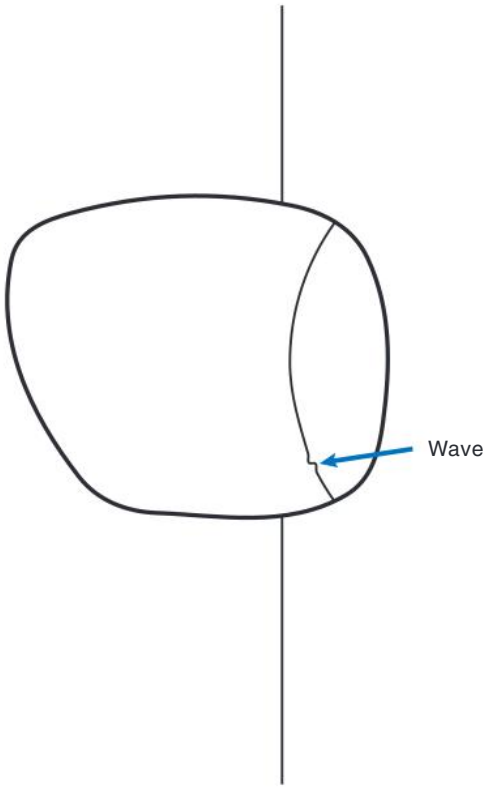

Figure 6.34 To inspect for a wave in the surface of a lens, view a grid or straight edge through the lens. Move the lens slowly so that the image of the line through the lens traverses across the surface slowly. An irregularity in the otherwise smooth image shows the presence of a wave.

Verification of Frames and Quality of Mounting

First check the quality of the mounting (the lens insertion). The security of the lenses will be revealed by the presence or absence of an air space between lens and frame. Check to see if the bevel is even or if chips or other defects are present at the edges of the lenses.

Check to be sure that the frame concurs exactly with all ordered specifications: (1) style and color, (2) eye size and DBL, and (3) length of temple. Be sure to inspect for possible frame damage, such as scratched or marred surfaces, or rolled frame rims.

Overall Verification

Check the extent of frame alignment (see Chapter 8). In many instances, frames will not be properly aligned but can be adjusted to standard alignment in the office. In some cases, alignment may not be possible because the frame is distorted or stretched too greatly or because the lens has been twisted because of an error in the position of the cylinder axis.

Errors that are adjustable in the office are probably best corrected by the dispenser. Much time is saved if the prescription does not have to be returned to the laboratory. Errors that cannot be corrected by the dispenser, however, should *not* be passed on to the recipient. This violates basic ethical principles, and it will eventually result in general dissatisfaction with the dispenser. It may also cause the laboratory to denote the dispenser as careless or unsuspecting. The dispenser who insists on correct and careful work from a laboratory generally receives it.

REFERENCES

1. Cook P. Has an Itch Got Your Goat? Product News, Diversified Ophthalmics, Cincinnati, OH, December 2011.
2. ANSI Z80.1-2020. American National Standard for Ophthalmics—Prescription Ophthalmic Lenses—Recommendations. Alexandria, VA, 22314: The Vision Council; 2021.
3. How bifocal adds should be measured, Ophthalmic Lens Data Series, Bausch & Lomb, undated.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. What is wrong with the formatting of this prescription?
OS: −4.25 −0.75 × 010
OD: −4.50 sph
- **a.** A leading zero is missing.
- **b.** There are not enough decimal places in the dioptric value(s).
- **c.** Right and left eye prescriptions are out of acceptable prescription order.
- **d.** A plus or minus sign is missing.
- **e.** The prescription is written acceptably.

2. What is wrong with the way the prescription for this lens is written?
+4.5 −1.0 × 017
- **a.** A leading zero is missing.
- **b.** There are not enough decimal places in the dioptric value(s).
- **c.** A plus or minus sign is missing.
- **d.** The prescription is written acceptably.

3. There is a problem with the way this prescription is written. What is it?
+0.50 −1.75 × 12
- **a.** A leading zero is missing.
- **b.** There are not enough decimal places in the dioptric value(s).
- **c.** A plus or minus sign is missing.
- **d.** The prescription is written acceptably.

4. What is the error in how this prescription is written?
+2.00 −0.75 × 033
- **a.** A leading zero is missing.
- **b.** There are not enough decimal places in the dioptric value(s).
- **c.** A plus or minus sign is missing.
- **d.** The prescription is written acceptably.

5. When reading a spectacle lens prescription with the lensmeter, which lens should be verified first?
- **a.** The lens with the strongest power in the 90-degree meridian.
- **b.** If the lenses have similar powers and prescribed vertical prism, then start with the lens with the most prescribed vertical prism.
- **c.** If it is not clear which lens is strongest and there is no prescribed vertical prism, then start with the right lens.
- **d.** All of the above are correct.

6. An individual with badly scratched lenses wants a new pair of glasses. You read the existing prescription from the old glasses to make the new pair. You also measure the wearer's PD. The distance between the OCs in the existing spectacles is found to be significantly different from the wearer's PD. Which of the following reasons for this is not a possible cause?
- **a.** There was an error in making the original glasses.
- **b.** There may be cylinder present in the prescription.
- **c.** There is prescribed prism in the original prescription.
- **d.** The power of the lenses in the 180-degree meridian is very small.

7. A wearer breaks her glasses. It is still possible to measure the lens power and distance between OCs in the broken glasses. The prescription is fairly high, and there is a large difference between the wearer's measured PD and the distance between OCs found in the broken glasses. The wearer cannot identify the prescriber or place where the prescription originated or where the glasses were made. In this case, the glasses should be made with:
- **a.** The new lens centers set at the wearer's measured PD.
- **b.** The new lens centers set at the same distance as the old lens centers were set.

8. In using a lensmeter, it is possible to find the power in either plus cylinder or minus cylinder form. Assume you are to find lens power in ***minus*** cylinder form. The correct procedure is listed below. For which of the step numbers listed below do we need to insert the word "plus" in the blank to make the procedure correct for minus cylinder form. The prescription you were reading had a power of +2.00 −4.00 × 015.
1. Turn the power wheel into the high _____ numbers.
2. Slowly advance the power wheel in the _____ direction.
3. Rotate the axis wheel to cause the sphere lines to come into focus first.
4. When in focus, record the sphere and axis values. (When reading this lens, the numerical values are equal to +2.00 and 015.)
5. Move the power wheel a second time, in the _____ direction, until the cylinder lines come into clear focus. (This numerical reading is −2.00.)
6. The difference between first and second power readings is the cylinder and is recorded as a _____ value.

- **a.** 1
- **b.** 1, 2
- **c.** 2, 5
- **d.** 2, 5, 6
- **e.** 1, 2, 5

9. A conventional crossed-line–target lensmeter is being used to find the power of a lens. To measure the prescription in plus cylinder form, begin by turning the power wheel:
- **a.** In the high plus direction.
- **b.** In the high minus direction.
- **c.** In either direction.

10. A lensmeter is used to measure a lens. The single line is clear at −3.00 D, and the axis wheel reads 020. With the axis wheel still at 020, the triple lines are clear at −2.50 D. Is this lens being read in plus or minus cylinder form?
- **a.** Plus cylinder form
- **b.** Minus cylinder form

11. True or False? The proper way to measure near addition power for front-surface segmented multifocal lenses is by turning the glasses around in the lensmeter so that the temples are pointing toward you, then measuring distance and near powers, taking the difference between the two as the near addition power.
    a. True
    b. False
12. When a lens is measured in the normal manner, with the back side of the lens against the lensmeter stop, the power being measured is called:
    a. The equivalent power
    b. The effective power
    c. The front vertex power
    d. The back vertex power
13. A lens has a front vertex power in the distance portion that reads +4.87 − 1.25 × 165. The front vertex power through the near addition reads +6.62 − 1.25 × 165. What is the add power?
    a. +1.25
    b. +1.50
    c. +1.75
    d. +2.00
    e. +2.50
14. It is necessary to order one lens only for a frame that cannot be sent to the laboratory. The frame is a common frame, and the laboratory has an electronic pattern shape for it. Leaving off what piece of information when ordering could result in a lens that is unacceptable optically?
    a. The "frame difference" measurement
    b. The height of the lens OC
    c. The ED of the frame
15. True or False? When making new lenses from an old prescription, the same lens material that was used in the old prescription should always be used in the new lenses.
    a. True
    b. False
16. As the power of the cylinder component of a prescription increases, the American National Standards Institute tolerances for how far the cylinder axis can be off mean that:
    a. High cylinder powers require the axis to be more exact.
    b. High cylinder powers allow the axis to be less exact.
    c. High cylinder powers require the same amount of exactness as low cylinder powers.
17. The American National Standards Institute recommends the following tolerances for acceptable limits of unwanted horizontal prism in a lens pair:
    a. If the PD is more than 2.5 mm off *and* horizontal prism exceeds 0.67 Δ, the prescription is outside of acceptable limits.
    b. If the PD is more than 2.5 mm off *and* horizontal prism exceeds 0.33 Δ, the prescription is outside of acceptable limits.
    c. If the PD is more than 2.5 mm off *or* horizontal prism exceeds 0.67 Δ, the prescription is outside of acceptable limits.
    d. If the PD is more than 2.5 mm off *or* horizontal prism exceeds 0.33 Δ, the prescription is outside of acceptable limits.
18. The American National Standards Institute recommendation for segment height in a mounted or unmounted lens pair is ____.
    a. ±0.5 mm for a single lens segment, with a difference in segment heights of this same amount between the two segments.
    b. ±1.0 mm for a single lens segment, with a difference in segment heights of this same amount between the two segments.
    c. ±1.5 mm for a single lens segment, with a difference in segment heights of this same amount between the two segments.
    d. ±2.0 mm for a single lens segment, with a difference in segment heights of this same amount between the two segments.
    e. ±2.5 mm for a single lens segment, with a difference in segment heights of this same amount between the two segments.
19. You are replacing a pair of scratched lenses—but not the frame—for a person who walked into your dispensary but had not obtained her prescription from you. The old glasses have a distance OC separation of 71 mm. You check the wearer's PD and find it to be 65 mm. The distance powers are −5.50 D sph for both right and left eyes. The wearer does not remember where she got her present glasses, but is definitely not wanting a new eye exam. ("I just got my eyes checked 6 months ago!") What would you order for the distance PD of the new lens pair?
    a. 65 mm
    b. 68 mm
    c. 71 mm
    d. Do a cover test and let that be the deciding factor.
20. The American National Standards Institute recommendation for near PD tolerance has both a prism diopter accuracy requirement and a millimeter accuracy requirement. The glasses must fail on both counts in order to fail. Regarding the millimeter accuracy, what is the allowable millimeter variation from ordered for a mounted lens pair?
    a. ±0.5 mm.
    b. ±1.0 mm.
    c. ±1.5 mm.
    d. ±2.0 mm.
    e. ±2.5 mm.

For the following questions (numbers 21 to 30), indicate whether the prescription is within tolerance according to the Z80.1 *Prescription Ophthalmic Lenses–Recommendations*. The prescription calls for the following:

R : −1.00 − 2.75 × 175

L : −0.25 − 0.75 × 004

add = +2.25

PD = 65/62

seg height = 21

However, when the prescription comes back from the laboratory, you find the variables to be as follows:

R : −1.37 − 2.65 × 178

L : −0.25 − 0.70 × 008

add = +2.25

PD = 69/64

seg height = 21.5

vertical prism shows 0.25Δ base − down OS

horizontal prism shows 0.10Δ base − in

Tell whether the parameter listed below is within the standards specified by the American National Standards Institute.

21. Right lens sphere pass?
    a. Yes
    b. No
22. Left lens sphere power pass?
    a. Yes
    b. No

23. Right lens cylinder power pass?
    a. Yes
    b. No
24. Left lens cylinder power pass?
    a. Yes
    b. No
25. Right lens cylinder axis pass?
    a. Yes
    b. No
26. Left lens cylinder axis pass?
    a. Yes
    b. No
27. Unwanted vertical prism pass?
    a. Yes
    b. No
28. Far PD/horizontal prism pass?
    a. Yes
    b. No
29. Near PD pass?
    a. Yes
    b. No
30. Seg height pass?
    a. Yes
    b. No
31. When measuring high amounts of prism, sometimes the illuminated target is displaced off the lensmeter screen. When this happens, with some lensmeters an auxiliary prism may be used to bring the target back on the screen. The base direction of the auxiliary prism is placed with its base:
    a. In the same base direction as the prism found in the prescription being measured.
    b. In the opposite direction to that of the prism found in the prescription being measured.
32. In trying to measure a lens, it is found that the prism amount present in the prescription is so high that the illuminated target is off the lensmeter screen. Using the prism-compensating device, the illuminated target must be moved onto either the horizontal or the vertical crosshair on the measuring reticle. This is done by using either only horizontal or only vertical prism. Which way should this be done?
    a. The larger of the two prismatic components is read from the prism-compensating device. The smaller prismatic component is read directly from the reticle.
    b. The smaller of the two prismatic components is read from the prism-compensating device. The larger prismatic component is read directly from the reticle.
    c. It makes no difference which prism element is read from the prism-compensating device or reticle.
33. Lens warpage is revealed by:
    a. Cylinder found on the front surface.
    b. Cylinder found on the back surface.
    c. Both a and b.
    d. None of the above reveals lens warpage.

7

Lens Insertion

AN OVERVIEW OF INSERTING LENSES INTO PLASTIC FRAMES

The steps involved in inserting a lens are standard for most plastic frames. The major variant is whether or not heat is used in the process—and if heat is to be used, how much heat is required. When no heat is used, the lenses are "snapped" into place. This is called *cold snapping*.

Adaptations of these basic procedures of lens insertion for special materials are explained later in the chapter. Table 7.1 gives an overview of lens insertion for different frame materials.

Lens Insertion Into Normal Plastic (Cellulose Acetate) Frames

Here are the procedures used to insert a lens into a plastic frame. Although these instructions are specific for cellulose acetate frame material, there is little difference in technique for other frames.

Heating the Frame

Lenses should be inserted into the frame without bumping the temples. When the endpieces of the frame are hot, if the temples are bumped, the hinge may loosen or become misaligned. Because most plastic frames have *hidden hinges* that do not go all the way through the plastic, a loose temple can be difficult to repair.

Before heating the frame, begin by noting the way the lens edge curves compared to the curve of the frame's eyewire (Figure 7.1). Since the lens edge often curves more than the frame's eyewire, it is advisable to preshape the upper and lower sections of the eyewire to conform to the curvature of the lens edge. This makes lens insertion somewhat easier.

Also, before heating the frame, it is advisable to do a "dry run." Hold the lens and frame in exactly the position you intend to use when actually putting the lens in the frame. You must be able to return the frame to this position immediately after it has been heated. Frames cool rapidly and lose pliability quickly. The few moments salvaged by this preparation may be vital. It is much better to hold the frame by the frame front and not the temples. Holding the frame by the temples vastly increases the possibility of loosening a hinge. Heat only the portion of the frame that is going to be manipulated. In the case of lens insertion, this is just one half of the frame front (Figure 7.2, *A*).

Hot Air Frame Warmers

Some frame warmers blow hot air onto the frame from both sides of a frame, and others only blow air from one direction. When using an air blower that blows from one direction only, be sure to heat both the front and back or top and bottom of the frame front alternately to prevent overheating any one portion.

- Regardless of how a frame is heated, here are some points to keep in mind.[1]
- Dark (especially black) frames heat more rapidly and are easily overheated.
- To allow for the frame to heat throughout the intended bend position, remove the frame from the heat periodically to let the surface cool slightly while heat is penetrating the core. Heat, reheat, repeat.
- Before inserting the lenses in a plastic frame, heat the thicker parts of the frame that surround the lens more than the thinner portions of the rim. That way there will not be uneven stretching.
- When adjusting a frame when the wearer is present, make sure it has cooled sufficiently before being worn.

Salt Pans

Salt pans can heat a frame quickly, but they can easily damage some lenses. A hot air warmer is the better option. If using a salt pan, first stir the salt to equalize the temperature. Then push some of the salt into a mound in one portion of the pan. Place the section of the frame to be heated just beneath the surface of the salt mound, leaving that portion not to be heated out of the salt and as parallel to the surface of the salt as possible (see Figure 7.2, *B*). Move the frame continually and very slowly while under the salt to avoid marking the soft plastic with salt granules. Do not permit the frame to become so heated that it sags or distorts. If salt sticks to a dry frame, additional talcum powder should be added to the salt. (The only two components of the "salt bath" are noniodized salt and ordinary talcum powder. Salt conveys heat well, whereas talcum powder prevents salt from lumping and sticking to the frame.) CAUTION: Because many frame materials are sensitive to excessive heat and coated lenses can be damaged by the high heat of salt pans, it is much safer to use a hot air blower rather than hot salt. An expensive antireflection (AR) coating can easily be ruined by using hot salt to heat the frame.

It is possible to use small *glass beads* with talcum powder instead of salt. The precautions are the same as with a hot salt bath. Any small beads stuck between the frame and lens do not dissolve when rinsing the frame and lenses. Stray beads on a hard floor could also result in slipping and a possible fall.

Inserting the Lens

As stated earlier, begin by noting the curvature of the lens edge compared with the curve of the eyewire of the frame as was shown in Figure 7.1. Heat the frame and preshape the upper and lower sections of the eyewire to conform to the curvature of the lens edge as shown in Figure 7.3.

TABLE 7.1 Comparing Lens Insertion by Frame Material

	Amount of Heat	Heating Methods	Edged Lens Size	To Shrink Material	Notes
Cellulose acetate	Use minimal heat until pliable.	Hot air best. Hot salt or glass beads acceptable.	On size or up to 0.5 mm above frame size.	Plunge in ice water. Frame will shrink if previously stretched.	Cellulose acetate is the standard material used for most plastic frames.
Cellulose propionate	Cold snap the lenses in place if possible. If not possible, use minimal heat.	When necessary, use a low heat setting (40°C/105°F) on an air warmer. Avoid using hot salt.	On size.	With too much heat, the material may shrink.	May help to heat a little at a time to avoid overheating.
Carbon fiber	None to minimal heat. Preferred insertion method: cold snap.	When heat used, use hot air at low temperature.	On size to just slightly larger in some cases.	Material does not shrink.	Types of carbon fiber material will vary. So will heat and insertion techniques.
Polyamide	No heat. Cold snap lenses in place.	Hot air for temples only.	Exactly on size.	Material shrinks slightly when heated.	After insertion, loose lenses may be tightened by heating the frame slightly.
Polycarbonate	No heat.	Cold snap.	On size.	Material does not shrink.	Material does not adjust.
Optyl	High heat. Use heat until material bends under its own weight.	Hot air, high temperature.	Oversize. This can be as little as 0.2 mm oversize for glass lenses and 0.4 mm oversize for plastic lenses.	Material will not shrink but instead expands with heat. Gradually returns to size as temperature cools.	Material returns to original shape when reheated. Quick cooling stops shrinking process and results in loose lenses.

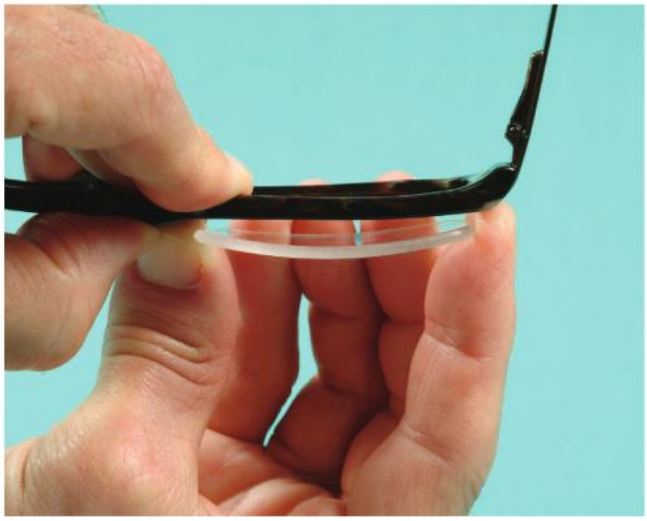

Figure 7.1 The top edge of the frame is compared with the top edge of the lens. If the frame is first curved to conform to the lens, the result will be more cosmetically acceptable. Shown here, the curve of the frame's upper and lower rims needs to be increased to match the curve of the lens.

Method 1—Insert the temporal (outer) edge of the lens into the corresponding portion (outer edge) of the frame (Figure 7.4, *A*). With the thumbs on the surface of the lens and the fingers on the nasal (inner) edge of the frame eyewire, snap the lens into the frame from the nasal (inner) side by applying pressure with both the thumbs and fingers (see Figure 7.4, *B*).

Method 2—Insert the upper outer (temporal) edge of the lens into the frame groove (Figure 7.5, *A*), push the upper inner (nasal) edge into the eyewire so that the whole upper edge of the lens is in the frame (see Figure 7.5, *B*), push the lower temporal edge in (see Figure 7.5, *C*), and conclude by snapping the lower nasal corner in (see Figure 7.5, *D*). (See Table 7.2 for a review of these methods.)

Most frame construction makes it easier to insert lenses from the front. Lenses should definitely be inserted into safety frames from the front so they will not be as likely to come out of the frame when struck from the front.

With either method, if the frame cools too much before the lens is fully inserted, it is advisable to fully remove the lens before reheating the frame. Many new to the process hate to "waste" all of their effort and try to heat the frame with the lens halfway in. That is not a good idea. The lens acts as a "heat sink" and prevents the frame from heating where the heat is needed. A heated lens is difficult to handle; also, a frame without lenses heats more uniformly and will stretch more evenly as the lens is inserted.

When pulling the eyewire using any of the methods, the pulling action must be *straight* and caution must be taken not to "*roll*" the eyewire. This rolling results in the front of the eyewire covering less lens than the back, or vice versa, as if the groove were turned at an angle (Figure 7.6). A rolled eyewire holds the lens less securely and disturbs the finished appearance of the spectacles. It also may cause some visual disturbance if the lens bevel is revealed and refracts light.

If, during the insertion procedure, the eyewire appears to become rolled, remove the lens and straighten out the rolled portion of the eyewire. Then, reinsert the lens.

After inserting the lenses into a conventional plastic frame (made of cellulose acetate) and checking for adjustment, it may be helpful to plunge the frame and lenses into ice water to "set" them. This procedure

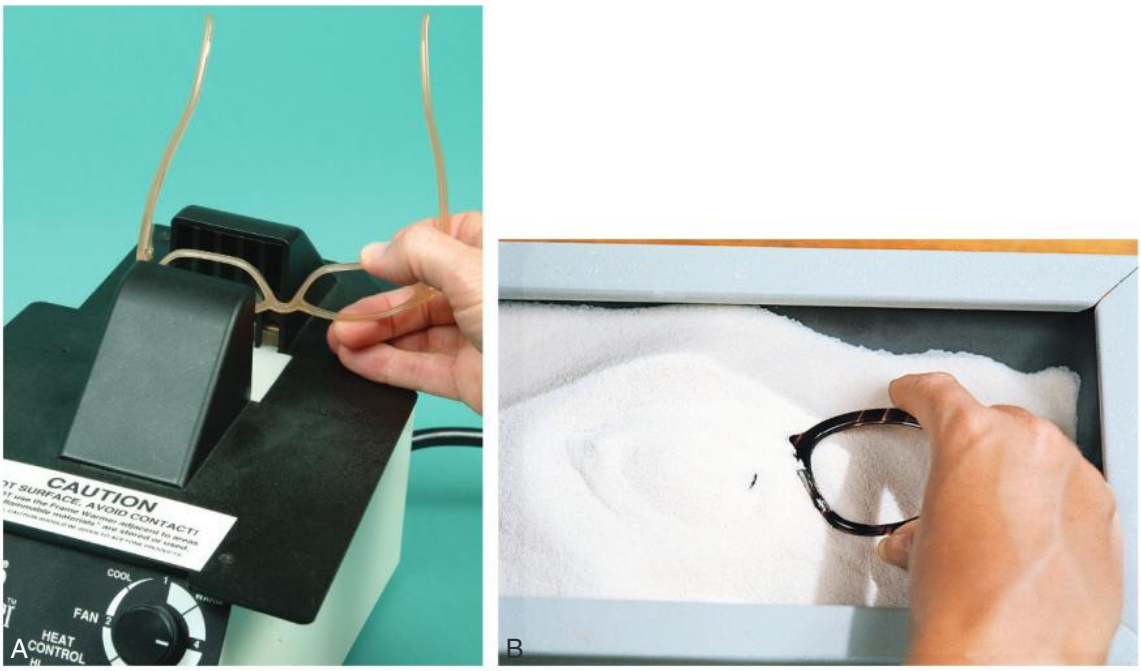

Figure 7.2 **A,** Heat only that portion of the frame that is going to be manipulated. Here, a hot air frame warmer is being used to heat the frame. Hot air is the safer method of heating a frame compared with hot salt. **B,** If hot salt is to be used, the frame should be moved slowly under the surface of the salt to help heat it uniformly. Moving the frame also causes it to heat faster, since heat is continually leaving the salt immediately adjacent to the frame and entering the plastic. (Remember that with newer plastic frame materials and many lens treatments, it is not safe to use a salt pan.)

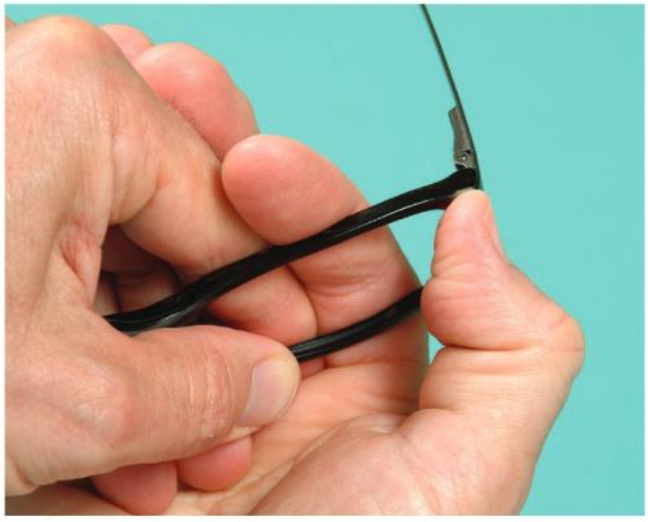

Figure 7.3 To make the frame rim fit the lens better, preshape the rims to conform to the curvature of the top and bottom of the lens edges.

shrinks the frame and may help to prevent loose lenses later. Be sure, however, to check the insertion and all adjustment points before "setting" the lenses. A notable exception for using this treatment is the Optyl frame that shrinks as it slowly cools. Plunging such a frame in cold water stops the shrinking process and can result in loose lenses.

Adapting for a Lens That Is Too Small

If new lenses have been ordered for an old frame, they may be too small if the frame has been stretched around its old lenses. In these cases, it may be possible to shrink a regular plastic frame to reduce the circumference of the eyewire to accept the new lenses firmly.

First, heat the frame front thoroughly until it is quite pliable. Then, immediately immerse it in very cold water—as cold as possible, using ice cubes if available. Allow the frame to rest in the cold water until it is completely cold to the touch.

If the frame is still too large, repeat the process two or three times. If the frame is still too large after the third treatment, the technique probably will not succeed.

This process can also be used on new frames, although they rarely respond more than slightly.

Checks After Lens Insertion

After inserting lenses, check that they are entirely in the groove of the eyewire. Be sure the eyewire is flat or uniformly rounded on the outside; if it is slanted, the eyewire has been rolled. A roll can be corrected by heating that portion of the eyewire involved and either twisting it with the fingers or pressing the frame against a flat surface using a counterrolling motion. If uncorrectable by this method, it is best to remove the lens and correct the lower eyewire without the lens in it. Then, reinsert the lens properly after heating the frame.

Compare the eyewire containing the lens with the empty eyewire adjacent to it. Be sure the lens fits squarely all around and has not been twisted. Note whether or not the shape of the eyewire containing the lens still matches the shape of the empty eyewire. Observe the upper rim near the bridge and compare it with the empty side. If the plastic is humped or stretched in comparison, the lens is not matching the eyewire shape and is probably altering the initial frame shape (Figure 7.7).

When both lenses have been inserted, an empty sample frame of the same shape may be used to assess the inserted pair. This may be necessary, especially for an untrained eye, because the lensmeter will not reveal a twist of the lens in all cases, such as when the lenses are spherical or if the bridge or endpiece is askew.

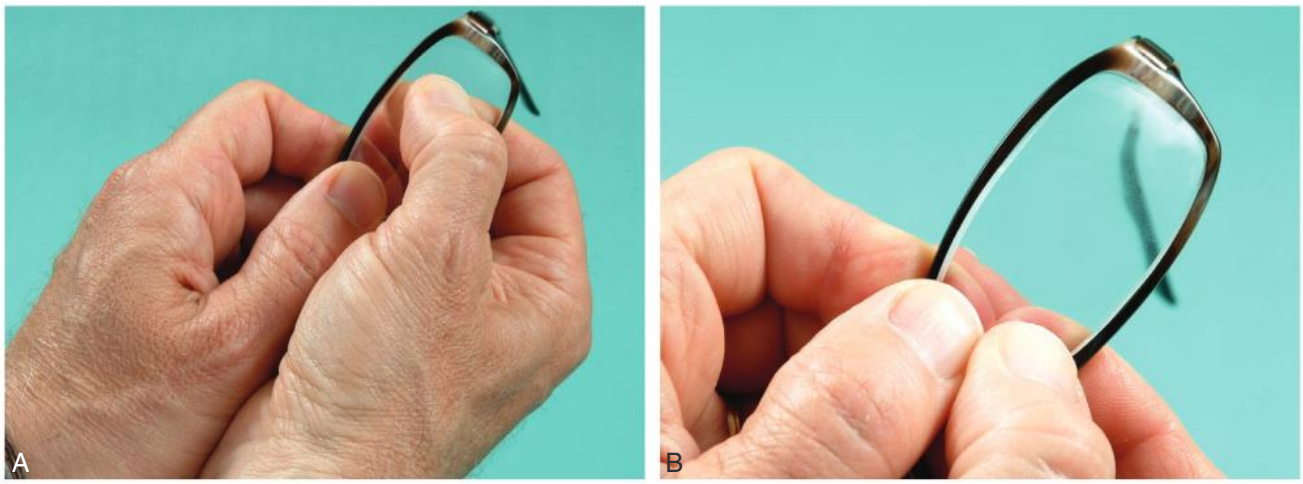

Figure 7.4 Method 1. **A,** Place the temporal edge of the lens in the frame groove. (The first moments of lens insertion are crucial in proper alignment of the lens bevel with the frame groove and must be done quickly.) **B,** The lens should snap in place fairly easily. If extreme force must be used in attempting to snap the lens in place, the process is better carried out using method 2.

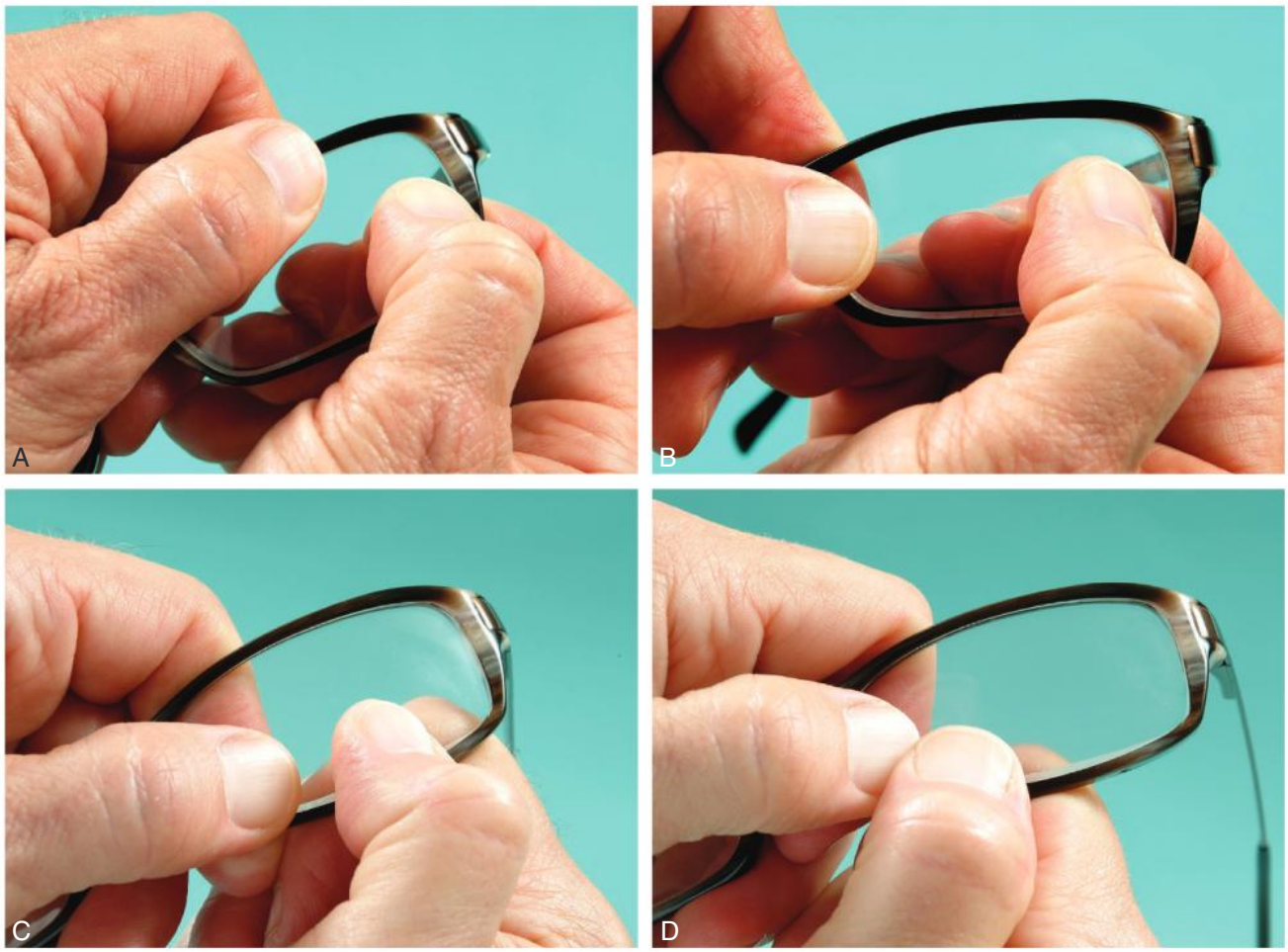

Figure 7.5 Method 2. **A,** Method 2 also starts with alignment of the lens bevel and frame groove, beginning in the upper temporal corner. **B,** When the upper and lower rims of the eyewire have been preshaped to the lens configuration, lens insertion into the entire upper half of the frame may be completed well before the frame cools. **C,** When the upper part of the lens is in the frame, start temporally and begin pulling the lower eyewire around the lens. **D,** Conclude the insertion process by snapping the bevel of the lower nasal part of the lens into the groove.

TABLE 7.2 Procedures for Inserting Lenses Into Plastic Frames

Method 1	Method 2
1. Heat and curve frame top to match lens top	1. Heat and curve frame top to match lens top
2. Heat eyewire	2. Heat eyewire
3. Place outer part of lens in outer part of frame	3. Place upper outer edge of lens in frame
4. Push inner edge of lens in with thumbs	4. Place upper inner edge of lens in frame (top of lens is now in frame)
	5. Pull the lower eyewire around the lens beginning temporally and ending nasally

Figure 7.6 This insertion attempt caused the lower eyewire to be rolled forward.

Figure 7.7 After putting the first lens in the frame, lens orientation for the inserted lens should be compared with the empty eyewire. This frame shows too much temporal upsweep.

Lens-twisting pliers (Figure 7.8) are used to correct a rotated lens. First, heat the frame and inspect the lens and pliers to be sure that all surfaces are free of salt. Hold the frame in one hand with the upper eyewire toward the palm. When working on the lenses, the forefinger, second finger, and thumb should grasp the area around the endpiece while the third and little finger brace the bridge area (Figure 7.9). Using the pliers to hold the lens, rotate the frame so that the upper eyewire always remains toward the palm when shifting from one lens to the other.

The pliers should grasp the lens close enough to the lower eyewire to prevent contact between the eyewire and the metal of the pliers. If the pliers press against the hot eyewire, they will invariably dent it.

Figure 7.8 Many different types of *lens-twisting* pliers are available. There are two important variations in these pliers. One is the "throat depth" of the pliers. The farther the pads are from the central joint of the pliers, the less likelihood there is of inadvertently marking the frame in twisting. The second variation is the vertical dimension of the pads that grip the lens surfaces. Some pads will be too large vertically for frames with narrow vertical depths to the lens.

Figure 7.9 Here, the frame is being held correctly. However, carelessness in holding the frame results not only in a rotation of the lens but also in a twisting of the frame bridge.

The same lens adjustment can be made using the fingers of the free hand instead of the pliers to grasp the lens. This adjustment is more difficult and must be performed immediately after lens insertion before the frame has cooled.

Checking a Bifocal or Progressive Addition Lens

With *straight-top bifocals*, the position of the lenses can easily be checked using a straight edge. This is placed horizontally across the front surface of the lenses at the level of, and parallel to, the straight tops of the bifocal segments.

If both lenses are correctly inserted, both segment tops will run adjacent or parallel to the straight edge. If one or both lenses are improperly

Figure 7.10 If the bifocal is a straight top, both bifocal lines will run parallel to the straight edge. Here, there is an error present, and the left lens is obviously twisted. Note that parallel bifocal lines do not guarantee that the lenses are not twisted in the frame. The frame front should still be examined for temporal upsweep or nasal humping.

inserted, the segment top of one lens will appear at an angle to the straight edge when the straight edge is parallel to the segment top of the other lens (Figure 7.10).

If the segment tops of the lenses are parallel but one lens still appears poorly positioned by the criteria previously mentioned (comparing the frame with lenses versus an empty frame), then the lens blank has been edged in a rotated position. The error cannot be corrected by adjustment; it requires the manufacture of a new lens.

By holding the lenses back to back, it is possible to determine before insertion if either bifocal lens has been edged in a rotated position. The bifocal portions should overlap exactly if equal seg height, decentration, and monocular interpupillary distances (PDs) were ordered (Figure 7.11). This is true for any type of segmented multifocal lens.

These same strategies may be used with progressive addition lenses that still have lens markings in place. There are two circles or other marks that denote the 180-degree line. These may be used to check for lens straightness just like the tops of bifocals were.

Judgment of *round-seg bifocals* depends a good deal on noting whether the lenses look like they are straight in the frame and not rotated. (Again, compare the frame with lenses versus an empty frame.)

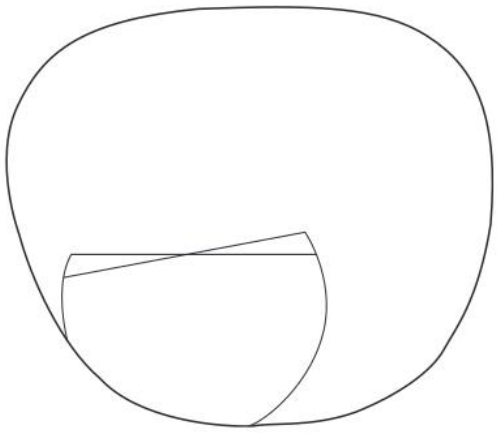

Figure 7.11 When two lenses are held back to back, any error in lens rotation becomes immediately evident. The same technique may be used to check a "lenses only" order when one bifocal seg has been ordered a different height from the other. Their differences will be obvious and measurable.

A good reference point for observation is the point where the nasal edge of the seg meets the eyewire. If both bifocals were ordered with equal seg height and decentration, the inner edges of the segs should meet the eyewires at symmetrical points. If one point appears higher up the eyewire nasally than the other, use the lens-twisting pliers to correct it, provided this adjustment does not place the cylindrical correction off-axis. If the axis is disturbed, the lens has been erroneously cut off-axis.

To be certain that *single-vision cylindrical lenses* are in the frame straight, preset the lensmeter at the correct sphere power, and set the axis adjustment wheel to the axis called for in the prescription. If the lines in the lensmeter appear to be off-axis, the lens has been inserted in a rotated or twisted position. Raise one side of the glasses, then the other, from the lensmeter table until the lines in the lensmeter appear straight and unbroken (Figure 7.12). Note the angle at which the frame is sitting, keeping in mind that the rotated lens has now been turned to the proper axis position. (In essence, the frame needs to be twisted around the lens until it sits flat on the lensmeter table again.) To bring the lens to its proper position, dot the lens with the lensmeter marking mechanism. Then, heat the eyewire and twist the lens around until these three dots are horizontal in the frame. The lens is then at its proper axis, which should also result in a symmetrical looking frame.

If there is nasal humping or a temporal upsweep present for one lens but not the other, the lens has slipped in the edging process or was improperly positioned at the time of the original edging. The only alternative is a new lens.

After the lenses are straight in the frame, adjust the frame into standard alignment.

Removing a Lens

To remove a lens, heat the frame front and place the thumbs on the back side of the lens in the lower, nasal area (Figure 7.13). Brace the front of the eyewire with the fingers. A towel may be placed around the lens to prevent burning of the fingers. (Lenses that were inserted with a cold snap method will also be removed cold.) Push the lens in one direction by pressing with the thumbs and bracing or pulling the eyewire in an opposite direction with the fingers.

Insertion Into a Cellulose Propionate Frame

Cellulose propionate material is very similar to cellulose acetate. However, it is more heat sensitive. It may even be advisable to cold snap the

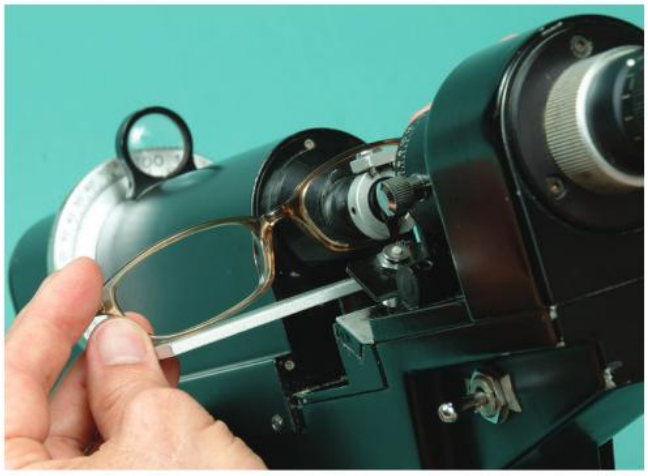

Figure 7.12 Ordinarily, during verification, glasses are positioned to rest flat on the lensmeter table. To aid in determining which way a rotated lens should be turned for lens realignment, it may be helpful to set the instrument at the desired axis and rotate the glasses until the target aligns correctly.

Figure 7.13 To remove a lens, pressure is applied to the back of the lens at the lower nasal portion.

lenses in place. When using heat, the frame warmer should be set for a low temperature (40ºC/105ºF). The closer the edged lens size is to the frame size, the less heat will be necessary. For that reason, it may be helpful to edge the lenses "on size." Because it is not always possible to tell a cellulose propionate frame from a regular plastic frame and because a number of other frame materials are also sensitive to heat, it is generally advisable to heed the following[2]:

- Use the lowest amount of heat necessary to accomplish the task.
- Heat the frame only until it is pliable; not until it actually softens.
- Never leave any frame unattended in a frame warmer.

Insertion Into a Carbon Fiber Frame

There are many different carbon fiber frames on the market. The actual material will vary depending on the manufacturer. This means that the properties of the material will vary some as well. The recommendations of the individual frame manufacturers should be followed.

Great care must be taken if carbon fiber material is heated. Carbon fiber material does not lend itself to adjustment. Although carbon fiber will become somewhat pliable with heat, the recommended method of lens insertion for carbon fiber fronts without eyewire screws is to cold snap the lenses in place.

Cold snap lens insertion is just what its name implies. The lenses are cut to fit the size of the frame exactly. The frame front is not heated. Instead, the lenses are inserted without heat. They are pushed into the frame in the same manner as they would be for a normal plastic frame. Pressing on the lens "snaps" the lenses into the "cold" frame.

Because of the reputed tendency of a standard CR-39 plastic lens to shrink very slightly over time, some labs use a small amount of heat to insert the lens. The lens may then be ground slightly larger. If heating carbon fiber material, it is much better to use hot air instead of salt or glass beads. A hot air warmer should be on low temperature and the frame heated for 10 to 20 s. Be advised, however, that "heat can soften the frame finish, making it easy to scrape the coated surface with the sharp edges of the lens. This can result in a frame that is chipped or flaked, exposing the dull base material.[3]"

A few carbon fiber frame fronts may come with an eyewire screw like that found in regular metal frame fronts. The screw opens and closes the eyewire to accept the lens. Lens insertion is done as if the frame were a metal frame (see *Lens Insertion Into a Metal Frame* later in this chapter).

Insertion Into a Polyamide Frame

Most of the guidelines for working with carbon fiber frames also apply to polyamide frames. The nylon-based polyamide material is thin, light, and resists adjustment. The lenses should be sized exactly and cold snapped into place. Oversized lenses simply will not go in, since the material will not stretch. One of the unique features of this material is its tendency to shrink slightly when heated in excess of 110ºC/230°F.[4] Therefore, heating a polyamide frame to insert a correctly sized lens will cause problems. A correctly sized lens would then be too large for the frame. On the other hand, this tendency to shrink somewhat can be an advantage if a lens is a bit too small. After the lens has been cold snapped into place, the lens fit can be tightened by heating the lens and frame together. The polyamide shrinks, and the eyewire contracts around the lens. Do not plunge the frame into cold water.

For polyamide frames, it is best to use a hot air type of frame warmer even when adjusting the temples.

Insertion Into a Polycarbonate Frame

Polycarbonate material is used for certain sports eyewear frame fronts. Polycarbonate does not adjust. Because polycarbonate does not become pliable when heated, lenses must be cold snapped into place. Lenses should be cut close to the actual frame size, since polycarbonate neither stretches nor shrinks.

Insertion Into a Kevlar Frame

Kevlar is also a nylon-based material. It neither stretches nor shrinks with heat but does exhibit a degree of pliability. This pliability allows for a more conventional lens insertion. In other words, the lenses do not have to be cold snapped into place. Yet the lenses still need to be cut exactly to size, or insertion will prove troublesome.

Insertion Into an Optyl Frame

Optyl, first developed in 1968 by Wilhelm Anger Co. of Traun, Austria, is a material that belongs to the group of epoxy resins. Optyl frames are cast molded rather than cut. They are also 20% to 30% lighter than the more conventional frame materials.[5]

Optyl frames can be identified by trade name and by the characteristic clear colors in which the material is made. The temples may or may not be made from the traditional Optyl material and should be adjusted according to the recommendations of the manufacturer for that particular frame.

Because Optyl will not shrink, it is better to cut the lenses slightly oversize. That amount is 0.4 mm larger for plastic lenses and 0.2 mm larger for glass lenses.[6,7]

Frames made from the original Optyl material do not begin to soften until the heating temperature reaches 80°C/176°F; they can safely be heated to a level of 200°C/392°F without bubbling or distorting. Should the frame become distorted, it will go back to its original molded shape on being heated. This can be an advantage when the frame is distorted during lens insertion, but it can also be a disadvantage during frame adjustment because heating the frame may cause it to lose its adjustment and go back to its original molded form.

To allow lens insertion, the frame should be heated until pliable enough to bend of its own weight: usually about 30 to 60 s. The lenses are not so much pushed into the eyewires as placed in them. If the eyewires are not properly surrounding the lenses, the frame should be reheated; the eyewires will adapt to the lenses as the frame attempts to resume its original molded shape.

The lenses must never be forced into a frame that has not been heated to pliability, nor should the frame be plunged into cold water to try to shrink the plastic about the lenses. Optyl expands with heat and returns to size through slow cooling. Plunging the frame into cold

water stops the shrinking process and has the exact opposite effect of that desired.

If a glass lens is off-axis or inserted in a rotated position, it should be rotated into its proper position only after the frame has been reheated—never while cold. If the lens is plastic, however, it should be removed and reinserted. If plastic lenses are not removed but only rotated, they will be loose after the frame and lenses cool.

Frames made of the original Optyl material do not bend while cold. Attempts to adjust them without heating almost always result in breakage. Since the material bends only when heated, properly adjusted Optyl frames tend to stay in adjustment until again heated.

To adjust the frame, heat only the portion of the frame requiring bending. Since this may be difficult to do for limited areas, use a heating unit that can direct heat only to a small area, such as a forced-air unit with a cone attachment that directs the flow of heat. Hold the frame so that the portions adjacent to the area being heated are protected from the heat and so they will not lose their adjustment.

LENS INSERTION INTO A METAL FRAME

Lenses to be inserted into a metal frame must be edged to the exact size. Therefore, it is more likely that the order will be correct if the laboratory has the wearer's actual frame. In certain instances, however, it may be necessary to order "lenses only." When ordering "lenses only" for a metal frame, then the dispensary must trace the lenses using a remote frame tracer and send the digitized shape to the lab electronically.

If there is not a frame tracer in the dispensary, the laboratory must have the plastic or electronic pattern for the frame in question. If there is any doubt about whether the laboratory has the pattern, they should be asked before the order is sent. Without an exact pattern, the frame will have to accompany the order. Once it is determined that the laboratory has the pattern, the chances of getting a good fit for a "lenses only" order are increased by measuring the circumference of the existing lenses. (This is explained in Chapter 6.)

To put a lens in a metal frame, begin by comparing the top and bottom curves of the lens to the corresponding curves of the upper and lower frame eyewires. If they do not match, the lens bevel will not seat squarely in the eyewire groove. Although in most cases these curves will match closely enough to allow a good lens fit, it will occasionally be necessary to use *eyewire forming pliers* (Figure 7.14) to reshape the frame eyewire. Eyewire forming pliers have curved nylon jaws. To increase the curvature of the eyewire, position the pliers as shown in Figure 7.15 and

Figure 7.14 Eyewire forming pliers are used to cause the frame eyewire to conform to the curvature of the lens edge.

Figure 7.15 To increase the curve of the eyewire of a metal frame, position the eyewire forming pliers as shown in the photo and gently squeeze, repositioning the pliers as necessary.

squeeze lightly. It may be necessary to continue to reposition the pliers stepwise along the upper and possibly lower eyewire until the new curve is evenly formed. (If the eyewire has *too much* curve, the eyewire forming pliers may be reversed to take some of the curve out of the eyewire.)

The best policy is to remove the eyewire screw, put the lens in the rim, and replace the screw. Simply loosening the screw until it is possible to place the lens in the eyewire may cause the lens to chip during insertion. It is helpful to use *eyewire closure pliers* (Figure 7.16) to aid in seating the lens in the eyewire groove. With closure pliers it is also possible to tell if the lens will be of the correct size (Figure 7.17).

Once the lens is seated in the eyewire, the eyewire screw is tightened. Forcibly tightening the eyewire screw so that it places excessive stress on the lens may cause a glass lens to chip along the edge if struck, or it may cause a plastic lens to warp. Excessive edge strain may be checked using a colmascope. A colmascope is a set of crossed polarizing filters. The lens is held between the two filters.

Figure 7.16 Eyewire closure pliers are made to fit into the top and bottom of the eyewire barrel.

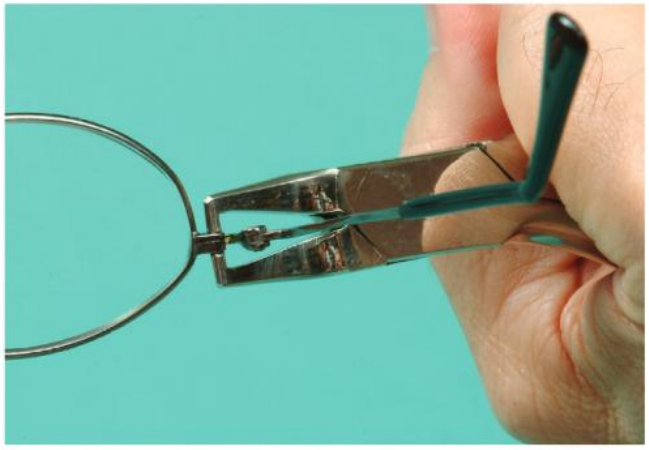

Figure 7.17 By using eyewire closure pliers to squeeze the eyewire around the lens, it is possible to see how well the lens will fit without having to replace the screw. Such pliers are especially handy in the edging laboratory.

LENS INSERTION INTO A NYLON CORD FRAME

An alternative to the traditional method of beveling a lens and inserting it into a grooved frame is the nylon cord frame. A *nylon cord frame* requires that the lens be made flat on the edge. A small groove is cut into the edge, usually all the way around the lens. A thin nylon string, attached to the frame, is slipped into the grooved lens to secure it in the frame. A nylon cord frame is also referred to by a number of names, including *nylon supra*, a *string mount*, *rimlon, Nylor*, and *suspension mounting*.

Mounting a new grooved lens in a nylon cord frame or replacing an old or broken cord on an existing frame requires similar procedures. Once the technique for replacing an old or broken cord is mastered, mounting a new lens in a new frame can be easily done. Therefore, *the first procedure outlined is that of replacing an old or broken cord. We are assuming that at least part of the cord is missing, so we will have to resize the cord to match the lens.*

Replacing a Nylon Cord of Unknown Length

1. *First, remove the old cord.* Sometimes it is difficult to remove the end of the cord from the frame groove because it has been wedged securely into the groove. If this is the case, a dental pick can be handy for pulling the end of the cord out of the frame groove (Figure 7.18).
2. *Pull out the old cord.* Next, catch the loop with the dental pick (Figure 7.19) and pull out the cord.
3. *Cut the new cord at an angle.* Since the old cord is missing and the length is unknown, start with a very long section of cord. Remember, whenever cutting the nylon cord, always cut the cord at an angle. Both ends of the cord should be cut at an angle to make threading easier and so that the cord seats nicely in the frame. Using a single-edged razor blade is best (Figure 7.20).
4. *Thread the cord into one side.* The cord will need to be attached to the mounting at two locations. Each point of attachment consists of two small holes. Some prefer to start with the nasal point of attachment, and others prefer the temporal point. For illustration purposes, we will start temporally.

   Starting with the temporal point of attachment, thread one end of the nylon cord into the *lower* hole from the *lens* side. Then thread the same end into the upper hole, leaving a length of 2.0 to 3.0 mm (Figure 7.21).

Figure 7.18 When it is difficult to remove a nylon cord from the frame channel of a nylon cord frame, a dental pick makes the job easier.

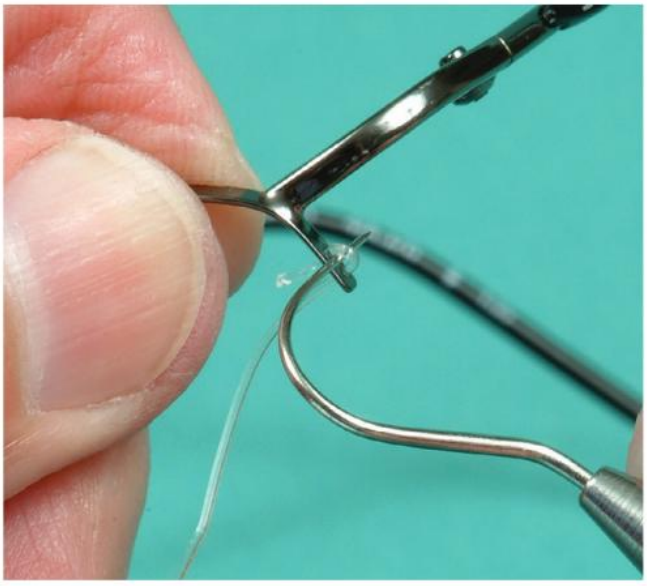

Figure 7.19 When removing an old cord from a nylon cord mounting, a dental pick can catch the tight loop to get the cord out of the holes.

5. *Size the cord to the lens.* Slip the other end of the cord through the lower hole at the nasal point of attachment. Do not thread it through the upper hole. Remember, the cord is first threaded from the lens side. With the end of the nylon cord still loose, slip the lens into the upper part of the frame. Thread the cord around the lens and pull the cord snug (Figure 7.22, *A*). Do not forcibly pull the cord so that it stretches.
6. *Remove the lens without "losing your place."* Hold the excess end of the cord with the thumb so that it does not slide out, and remove the lens. (Since the cord was not pulled tight, it should be possible

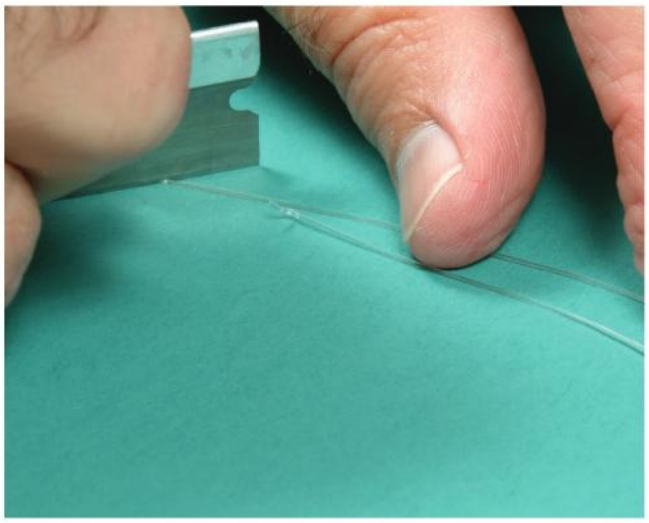

Figure 7.20 Cutting the nylon cord at an angle makes it easier to thread through the holes in the frame and allows it to seat smoothly in the groove under the lens. Here, the length of the new cord is being estimated from the old cord that broke off near the point of attachment.

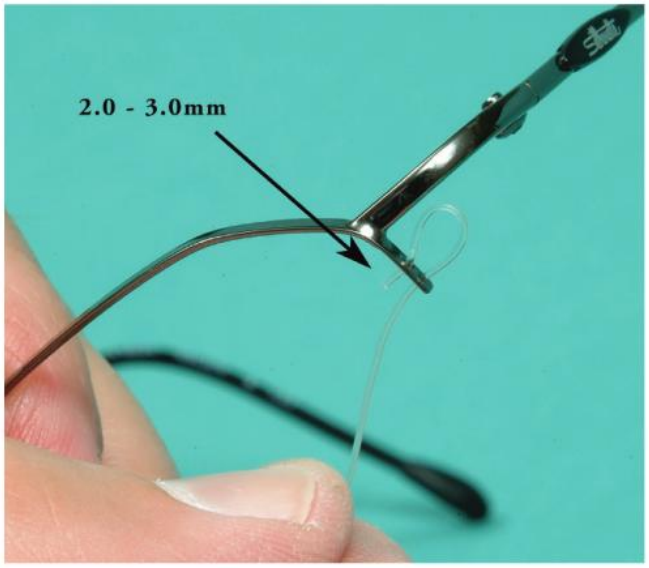

Figure 7.21 The cord is threaded into the lower hole from the inside and back into the upper hole.

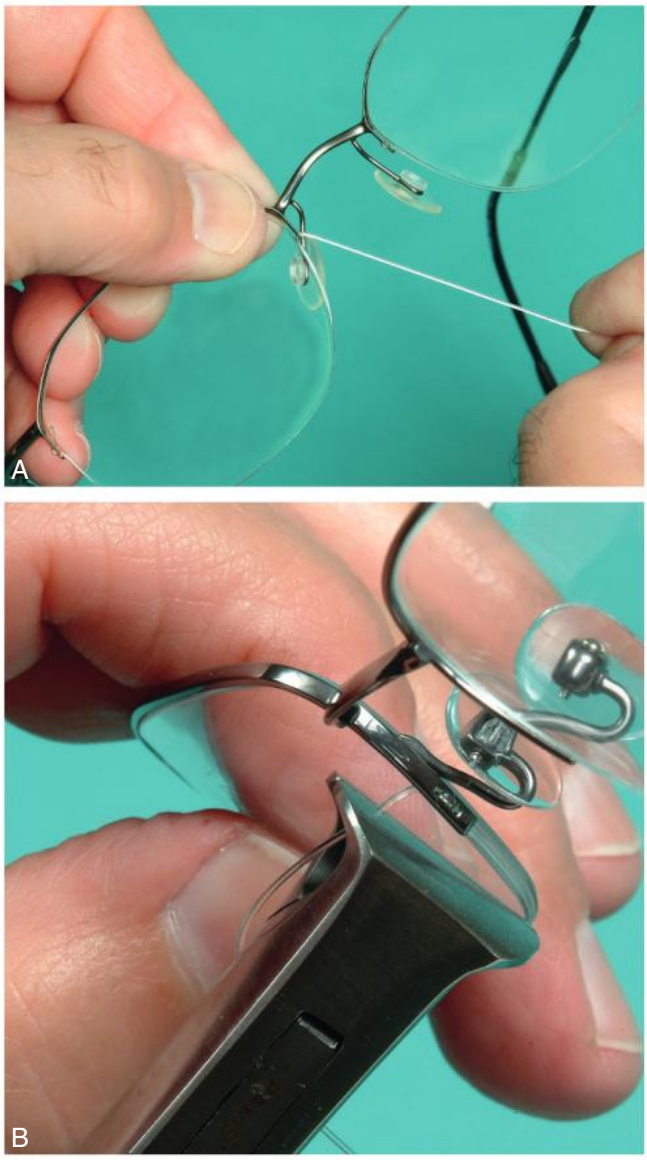

Figure 7.22 In this instance, we need to find the necessary cord length when the cord, or a good portion of the cord, is missing. When replacing a nylon cord of unknown length, the cord is pulled snug around the lens as shown in **A**. It should not be stretched. Next, the cord is cut to the correct length as shown in **B** and then threaded. A cord length of 2 to 3 mm is left to press down into the groove to help hold the cord securely against the lens edge.

to remove the lens without losing the point of reference for length on the cord.)

7. *Take up the slack in the cord.* Because the cord was not pulled tight around the lens, it is necessary to pull the cord 1.5 to 2.0 mm *farther* through the lower hole so that the lens will be tight enough.
8. *Thread the excess cord through the remaining hole.* Thread the excess cord through the upper nasal hole while maintaining the new position of the cord in the lower hole.
9. *Clip off the excess cord.* Clip the excess cord, leaving 2.0 to 3.0 mm to lay down inside the eyewire (see Figure 7.22, *B*). (If the cord is clipped at an angle, it may lay down in the groove more smoothly. Nail clippers work as well as regular cutting nippers.)
10. *Press the end of the cord into the frame groove.* First, press the cord into the frame groove with the thumb (Figure 7.23, *A*). To get it all the way into the groove, it is helpful to next use a pair of half-padded nylon jaw pliers to push the loose end of the cord down into the groove (see Figure 7.23, *B*). (Failure to fully tuck the cord into the groove will cause the lens to chip or flake because of the pressure of the cord between the edge of the lens and the edge of the eyewire.) Do this both nasally and temporally.
11. *Secure the lens in the upper half of the frame.* The lens is inserted into the frame beginning in the nasal area (Figure 7.24, *A*) and followed by the temporal area (see Figure 7.24, *B*). The lens should come in *behind* the nylon cord so that the cord rests on the front surface of the lens.
12. *Stretch the cord into the groove around the lens.* To secure the lens in the frame, the cord must be stretched to fit into the lens groove. This is done using a plastic strip. (Some use a fabric ribbon, however, a ribbon will often fray, leaving threads wedged between the

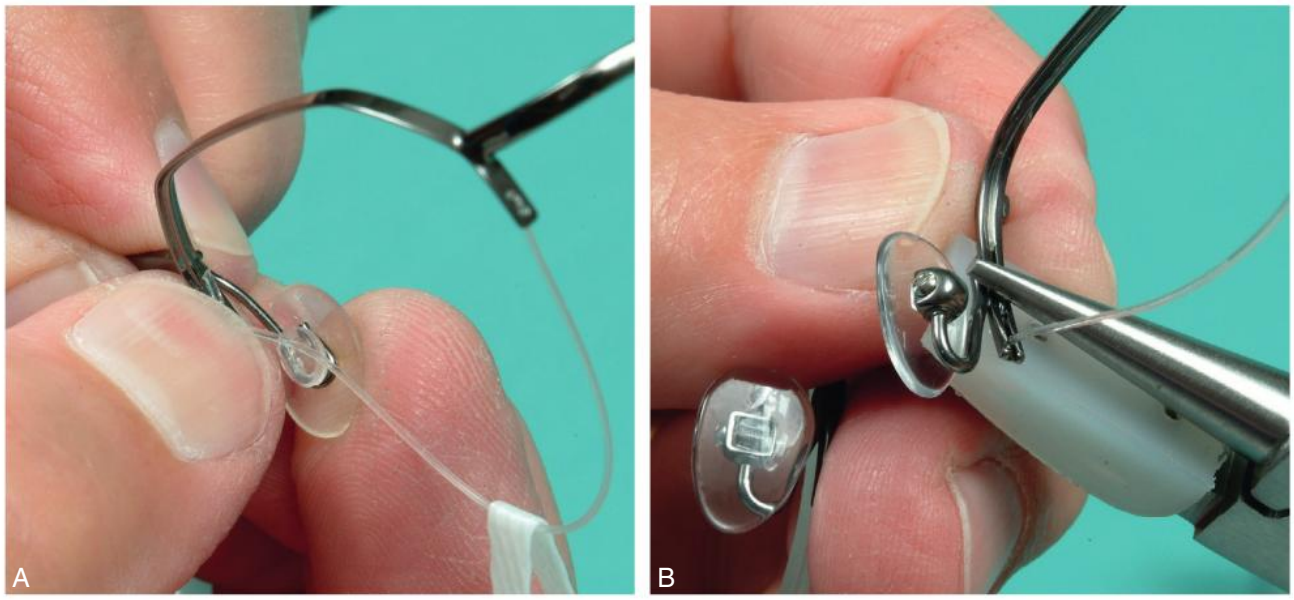

Figure 7.23 Before actually putting the lens in the frame, the end of the cord is pressed into the groove of the frame. In **A**, the end of the cord is being pressed into place with the thumb. This may not get the cord all the way in the groove but will get it started. In **B**, half-padded pliers are used to press the end of the cord fully into the groove.

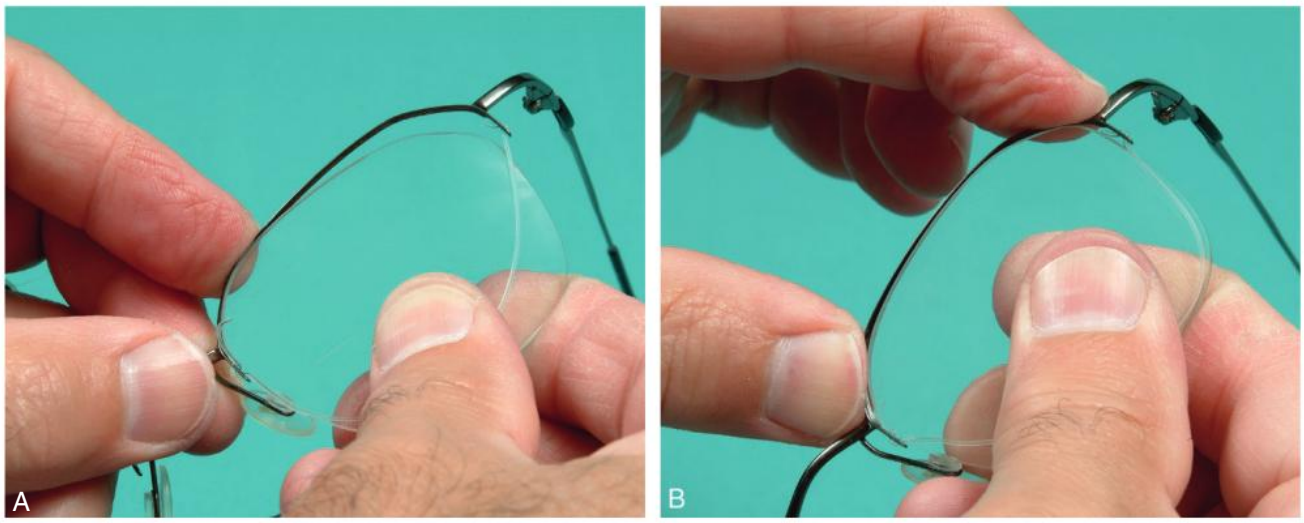

Figure 7.24 To put the lens in the frame, begin with the upper nasal corner as shown in **A**. Once the upper nasal corner of the lens is in place, the upper edge of the lens can be more easily aligned by moving across the upper rim as shown in **B**.

lens and the cord. It is extremely difficult to remove these threads.) Start out with the cord on the front side of the lens. Slip the plastic strip between the nylon cord and the lens, folding the strip back and grasping both ends together. Begin temporally, and use the strip to pull the cord around the edge of the lens, seating it into the lens groove on the way around (Figure 7.25).

(CAUTION: There are metal hooks made specifically for stringing lenses. The main hazard of these hooks is the possibility of causing a small flake of the lens to chip out at the groove area. When this occurs, the lens must be replaced.)

13. *Check the cord tension.* Cord tension can be checked in one of at least two ways:
    a. Check the tension at the corner of the lens right after the cord drops into the groove (Figure 7.26) or
    b. Check the tension of the cord by sliding the plastic strip toward the bottom of the lens until it is close to the midpoint of the lens cord. Pull fairly hard on the cord with the strip. The strip should pull the cord about 0.5 to 1.0 mm away from the edge of the lens.
14. *Try to rotate the lens.* Once the lens is in place, grasp the lens as shown in Figure 7.27 and attempt to rotate it in the frame. If the lens rotates easily, the cord is not tight enough.

    If the tension is incorrect, the lens should be removed and the length of the cord altered. (It may be necessary to use the dental pick to free the end of the cord from the frame groove.) Most often when the fit is wrong, the cord will be loose and will have to be shortened. If this is the case, repeat the previous steps beginning with Step 8.

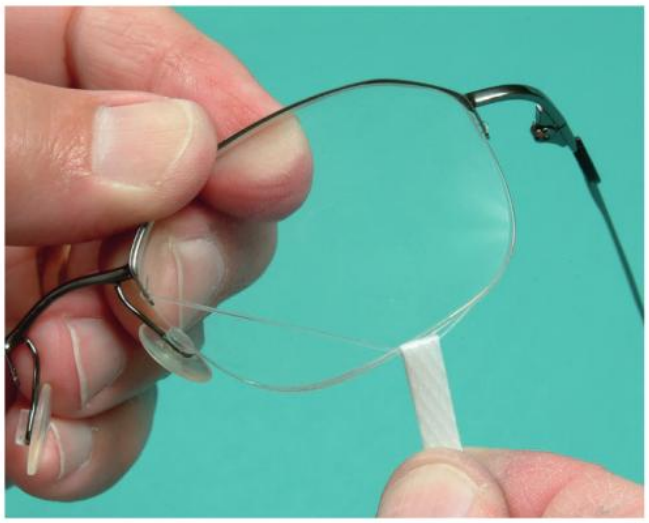

Figure 7.25 The cord must now be pulled around the lens. To slip the nylon cord into the groove of the lens, begin temporally, and pull the cord around the lens in a nasal direction. The cord must start out on the front side of the lens.

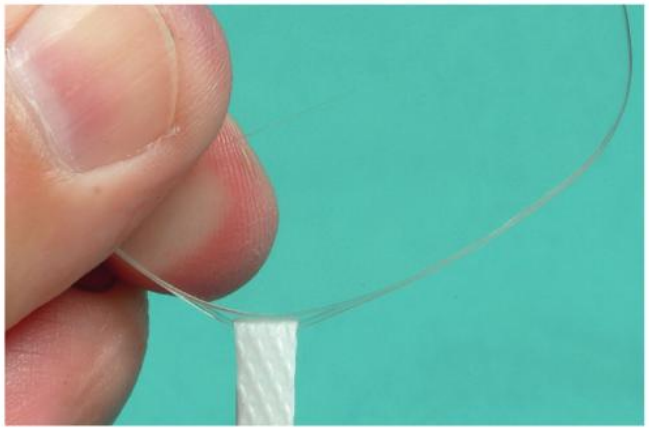

Figure 7.26 Pull fairly hard on the plastic strip to check the tension of the cord. As shown in the figure, the cord should stretch some, but there should be no more than 1.0 mm between the cord and the lens. (Some prefer to check for cord tension at the center of the bottom of the lens.)

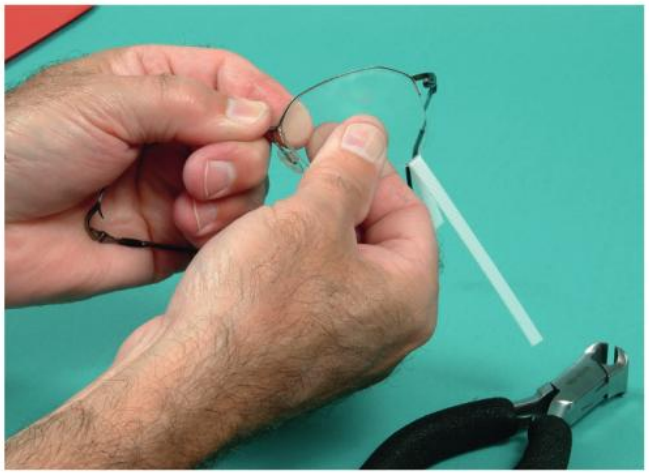

Figure 7.27 Once the lens is in, grasp the lens between the thumb and fingers, and try to rotate the lens. If the lens rotates easily, the cord is not tight enough.

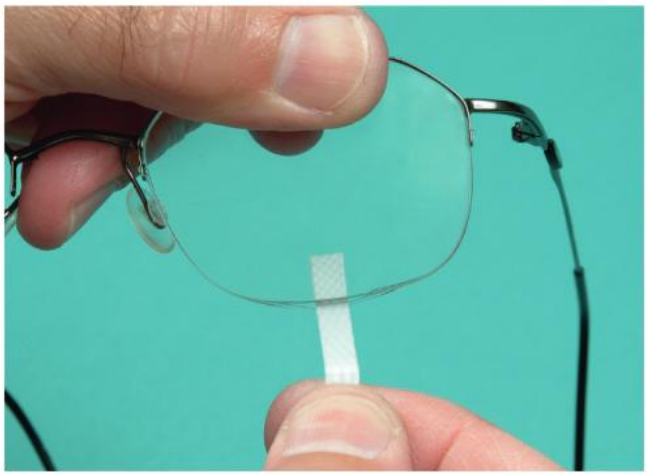

Figure 7.28 Move the strip to the center of the lens before attempting to remove it. If the strip is at or near a corner of a lens when being removed, it may pull the cord out of the groove.

15. *Remove the plastic strip.* Once the lens is securely seated, move the plastic strip to the center of the lens edge, release one end of the plastic strip, and pull it from between the lens and cord (Figure 7.28). Trying to remove the strip at a corner can pull the cord out of the groove. (For a review of these steps, see Box 7.1.)

Replacing an Old or Broken Nylon Cord

If the nylon cord is old or broken with both parts still intact, the new cord can be cut to match the length of the old cord. The procedure is basically the same as just described for replacing a missing cord, except that we can line up the new cord with the old cord and cut it to match. Remember to cut both ends of the new cord at an angle. If the old cord is in two pieces, line up the longest piece of the old cord and allow extra for the estimated length of the short piece of the broken cord. Cut the new cord to match.

Both temporal and nasal edges are threaded into the frame as described above. Hereafter the remaining steps are the same as previously described.

Cautions for Lenses With Thin Edges

When a lens used for a nylon cord frame has thin edges, the edge may not leave much room for the groove. This means that thin lens material on either side of the groove may have a tendency to chip, especially during insertion and removal. Plus-powered lenses and thin, high-index minus

BOX 7.1 Procedure for Inserting Lenses Into a Nylon Cord Frame

1. If necessary, remove the old cord.
2. Cut the end of the new cord at an angle.
3. Thread the nylon cord through the lower temporal hole from the lens side and continue through the upper hole, leaving 1.5 to 2.0 mm.
4. Put the lens in, and pull the cord snug to size the lens.
5. Hold the excess end of the cord with the thumb, and remove the lens.
6. Take up 1.5 to 2.0 mm of slack in the cord.
7. Thread the remaining cord through the upper hole.
8. Cut the cord off 1.5 to 2.0 mm past the hole.
9. Press the excess cord into the frame groove on both sides.
10. Insert the lens in the upper half of the frame.
11. Stretch the cord around the lower half of the lens using the plastic strip.
12. Check cord tension. (Cord should give 0.5 to 1.0 mm.)

lenses with narrow vertical dimensions may have notably thin edge areas. Here are some suggestions to avoid chipping thin lens edges[8]:

- When putting the nylon cord into the lens, if possible, start with the thinnest part of the lens, and finish with the thickest.
- To remove a nylon cord, do the reverse; start with the thickest part of the lens edge, and end with the thinnest.

Retightening a Loose Nylon Cord Lens

If a lens in an old nylon cord frame is loose or has fallen out, it is prudent to simply replace the cord rather than retightening the existing cord. Over time, an old cord may have lost some of its elasticity. The new cord will have more elasticity, and replacing the old cord avoids the possibility of it breaking later.

Some dispensers have resorted to removing the lens and heating the old cord. The heat will cause the cord to shrink. When the lens is reinserted, it will be tighter—but only temporarily. Tightening a lens in this manner is not a good practice. The cord will not remain tightened long, and the lens may fall out unexpectedly, this time to break or become badly scratched.

Nylon Cord Frames With Liners

Some nylon cord frames have liners that fit into the top eyewire channel of the frame. These liners are called *figure 8 liners* because, when viewed from the end (in cross-section), the liner looks like the number 8. One part of the 8 is smaller than the other.

If it is necessary to replace the figure 8 liner in the top eyewire, take a knife blade, file, or dental pick and dig into the liner, sliding it out either end. Measure the old length of liner, and cut a new piece of the same length. To aid in inserting the figure 8 liner back into the top eyewire, make sure the new piece is cut at an angle.

Using the smallest side of the figure 8 first and beginning either nasally or temporally, slide the liner into the top eyewire channel. Feed in the entire piece of liner, and center it in the channel. If the liner seems loose, turn it around and use the larger side. Care should be taken not to block any of the four holes used to hold the nylon cord in place.

Frames With Metal "Cords" for Rims

Some frames are made with very thin metal rims. When lenses for these frames are edged with flat edges and then grooved, the rim of the frame slips into the groove in the same manner as a nylon cord would. Because the metal rims are thicker than a nylon cord, the groove must be made wider than it would for nylon cord frames.

CLEANING FRAMES AND LENSES

In the past, the simplest method of cleaning frames and lenses was to immerse them in a mild detergent solution, rub with the fingers or a soft cloth, and dry with a soft, lint-free cloth. Difficult-to-remove lens spots were taken care of using acetone, with care being taken to avoid getting any acetone on the plastic frame. Now, however, the situation is not so straightforward.

Using some detergents as the last cleaning agent for AR-coated lenses is incorrect because some detergents contain additives. Use no detergent that contains citrus (which leaves a residue), and none having creams or abrasive material. Acetone should not be used on polycarbonate lenses.

Solvents used to remove the markings on progressive addition lenses can damage some frame component materials, so avoid getting any on the frame.

An acetone replacer is helpful to have since it is not considered a hazardous material and is an effective cleaner. One such brand of acetone replacer made by SeeGreen is available from Hilco as *Solves It* and *Solves All*. They are available in a bottle or in a felt-tip style pen to remove the markings from progressive addition lenses. They are safe on all lens materials, including polycarbonate.

Tables 7.3 and 7.4 summarize the cleaning agents that should be used or avoided for different frame and lens materials.

TABLE 7.3 Cleaning of Frames

Frame Material	Use	Avoid
Cellulose acetate Propionate Polyamide	Mild detergent* Ultrasonic unit with ultrasonic cleaning solution	Acetone or acetone replacers Alcohol†
Nylon Carbon fiber Optyl	Mild detergent Alcohol will work for stubborn spots Ultrasonic unit with ultrasonic cleaning solution	Acetone or acetone replacers
Polycarbonate	Mild detergent Alcohol Ultrasonic unit with ultrasonic cleaning solution	Solvents such as acetone
Metal	Mild detergent Alcohol Ultrasonic unit with ultrasonic cleaning solution	Acetone or acetone replacers (which may remove painted trim)

*A mild detergent is one that has no citrus (which leaves a residue), and no creams or abrasive material. A clear detergent, such as clear Joy, works well. Dawn is also a brand often recommended.
†Propionate material is sensitive to alcohol. Because it is difficult to tell the difference between cellulose acetate and propionate frames, it is safer to avoid alcohol.

Cleaning Instructions for Wearers

Knowing the cleaning procedures outlined in Tables 7.3 and 7.4 is a good starting point for speaking with people on how to clean their lenses. Here are some other points[9]:

TABLE 7.4 Cleaning of Lenses

Lens Material	Use	Avoid
Glass and CR-39 plastic	Mild detergent, alcohol, acetone, or acetone replacer such as *Solves It* or *Solves All**	Abrasives
Polycarbonate and high-index plastic	Mild detergent or alcohol such as *Solves It* or *Solves All**	Acetone
Antireflection (AR)-coated lenses	AR coating lens cleaner (It is possible to use a mild detergent first and then an AR coating lens cleaner.)	Detergents with citrus, creams, or abrasive material. Acetone Ultrasonic cleaning units

*Made by SeeGreen and available from Hilco.
AR, Antireflection.

- The best way to clean lenses is to first run water over them. This removes any gritty dirt. Then use a mild soap or mild dishwashing liquid like Dawn, and rinse them clean. Using lens cleaning solutions like found in optical dispensaries is always best. These lens cleaners will not contain any residues like some soaps. In fact, they will remove any residues left by soaps.
- Don't use hot water. Hot water can be hard on lenses with AR coatings.
- To avoid any stubborn build-up of oil or dirt between the lens and frame or around the nose pads, it can be helpful to occasionally overnight soak the spectacles in a glass filled with water and a few drops of Dawn dishwashing soap.
- Even though it sounds logical, avoid window cleaners like Windex. They are normally too acidic.
- Microfiber lens cleaning cloths are helpful for cleaning when there is no water available. They also work well for drying the lenses. If there is grit on the lens or cloth and the lens is cleaned dry, the grit can still cause microscratches. Microfiber cloths may and should be washed periodically.
- Hold the glasses by grasping the outside rims of the lens being cleaned. Holding one lens while cleaning the other will put unintended stress on the frame bridge.
- If the frame is round, or nearly so, don't clean the lenses with a circular motion. Instead use back and forth motion. Over time a circular cleaning motion will cause the lens to rotate. This will change the axis of a cylinder. If the lens has been decentered, it could also move the optical center of one lens upward and of the other lens downward. This causes unwanted vertical prism. To help head this off, some dispensers use an optical file to place a small mark on the rear bevel of each lens and corresponding marks on the back of the frame right next to the lens marks. Using these reference marks, the wearer can tell if a lens gets out of rotational alignment.

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PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. True or false? When inserting a lens, if success is not achieved on the first try, heat the frame and the partially inserted lens together and then push the partially inserted lens the rest of the way into the bevel.
   a. True
   b. False
2. If salt from a salt pan sticks to the frame, what may be done to alleviate the problem?
   a. Use newer salt.
   b. Have the heating element checked.
   c. Add talcum powder to the salt.
   d. Use a better product line of frames.
   e. Wash the frames ahead of time.
3. A pair of edged multifocal lenses are held back to back. Their segments overlap exactly. Which of the following may not always be true?
   a. The cylinder axes are correct.
   b. Neither of the lenses was edged in a twisted position.
   c. The segment heights are equal.
   d. The total segment insets are equal.
4. What type of frame may be heated until it bends under its own weight?
   a. cellulose acetate frames
   b. propionate frames
   c. Optyl frames
   d. carbon fiber frames
   e. polyamide frames
5. What frame material may shrink when plunged into cold water?
   a. polyamide
   b. cellulose acetate
   c. Optyl
   d. carbon fiber
6. What frame material may shrink slightly when heated?
   a. polyamide
   b. cellulose acetate
   c. Optyl
   d. carbon fiber
   e. propionate
7. Which frame material should *not* have lenses cold snapped into place when being inserted?
   a. polyamide
   b. Optyl
   c. carbon fiber
   d. polycarbonate
8. True or false? Polycarbonate frames neither stretch nor shrink when heated.
   a. True
   b. False
9. How much above size should a CR-39 plastic lens be edged for an Optyl frame?
   a. 0.4 mm larger
   b. 0.2 mm larger
   c. exactly on size
10. To remove the lenses after a cellulose acetate frame is heated, it is easiest to push a lens out by placing the thumbs on the:
    a. front side of the lens temporally, pushing the lens with the thumbs while pulling the eyewire with the fingers.
    b. front side of the lens inferior nasally, pushing the lens with the thumbs while pulling the eyewire with the fingers.
    c. back side of the lens centrally, pushing the lens with the thumbs while pulling the eyewire with the finger.
    d. back side of the lens superior temporally, pushing the lens with the thumbs while pulling the eyewire with the fingers.
    e. back side of the lens inferior nasally, pushing the lens with the thumbs while pulling the eyewire with the fingers.

11. Eyewire closure pliers are used
    a. to press a stubborn lens into an eyewire that is otherwise too small for the lens.
    b. to form the eyewire of a metal frame to the curvature of the top and bottom of the lens edges.
    c. to close the eyewire of a metal frame around the lens to allow for lens size evaluation.
    d. to grasp the eyewire of the frame while tightening the eyewire screw.
12. When restringing a nylon cord mounting, the ends of the cord are threaded through two holes in the nasal side and two holes in the temporal side of the frame. Which hole is threaded first?
    a. The cord is always threaded through the upper hole first.
    b. The cord is always threaded through the lower hole first.
    c. It does not matter which hole is threaded first.
13. We are inserting a grooved lens in a nylon cord frame. The nylon cord is the correct length and in the mounting. Now the upper part of the lens is pressed into the upper eyewire of the frame. When this is being done, where should the cord be?
    a. In front of the front surface of the lens.
    b. In back of the lens back surface.
    c. Cord position does not matter.
14. To get the end of a nylon cord out of the groove mounting when it is stuck in the groove, the best thing to use is:
    a. your fingernail.
    b. finger nail clippers.
    c. a tooth pick.
    d. a dental pick.
15. For a nylon cord frame, the tension of the cord is checked before removing the plastic strip used to slip the cord into the lens groove. The strip is positioned toward the bottom of the lens until it is close to the midpoint of the lens cord. The cord is pulled fairly hard with the strip. The strip:
    a. should pull the cord about 0.5 to 1.0 mm away from the edge of the lens.
    b. should pull the cord about 1.5 to 2.0 mm away from the edge of the lens.
    c. should pull the cord about 2.5 to 3.0 mm away from the edge of the lens.
    d. should not pull the cord away from the edge of the lens at all.
16. True or false? When the cord of a nylon cord frame has lost its elasticity, remove the lens and heat the cord. This will shrink the cord, retightening the lens. The lens will remain tight almost as long as it did after first being inserted.
    a. True
    b. False
17. When the lens is completely inserted into the frame bevel but the lower edge appears to be sticking out slightly, what is the most likely problem?
    a. The lens is too large.
    b. The lens is too small.
    c. The lens rim has been rolled.
    d. The frame is too old.
18. What type of lens will not normally give evidence of being twisted or rotated in the frame when being checked in a lensmeter unless the lenses have been decentered?
    a. A lens with a prism component
    b. A lens with a cylinder component
    c. A flat-top, spherocylindrical bifocal lens
    d. A lens that is simply spherical
19. A pair of glasses is being verified. One lens is obviously in a rotated position, yet the axis of the cylinder for this lens is correct when read on the lensmeter. What might be the cause?
    a. The lens was inserted incorrectly in the frame.
    b. The lens was too large and distorted the lens shape.
    c. The lens was edged off-axis.
20. What is the easiest way to check for a rotated lens after lens insertion of flat-top multifocal lenses?
    a. Check with the lensmeter.
    b. Place a ruler along the tops of the bifocal segments and see if both segment tops are parallel to the ruler edge.
    c. Check to see if the distance and near PDs match what was ordered.
    d. Check for equality of the major reference point heights.
21. If you were to be using acetone as a cleaning agent, you should avoid using it on all but which one of the following? (In other words, on which of the following can you use acetone?)
    a. Uncoated CR-39 lenses
    b. Polycarbonate lenses
    c. Cellulose acetate frames
    d. AR-coated lenses

8

Standard Alignment

STANDARD ALIGNMENT OR "TRUING" OF FRAMES

A frame received from an optical laboratory is supposed to have already been *trued* (i.e., brought into standard alignment). A frame in standard alignment has been adjusted to certain impersonal standards that are independent of the type of face to which it is to be fitted. Standard alignment is intended to ensure that adjustments required to fit the wearer are responsive to the wearer's physical characteristics and not to irregularities in the frame itself that may be produced while the frame is fashioned in the laboratory.

Some frames may not have received this adjustment in the laboratory. We will assume this to be due to an oversight, new personnel, or the absence of regular personnel. Regardless, it is essential that standard alignment be performed by the dispenser before attempting to adjust the spectacles for the individual wearer. The best time to preadjust is when the prescription is being verified.

Truing spectacles is a good starting point before adjusting them, whether or not they are being adjusted for the first time. This is especially applicable for spectacles that have been worn for a long time without recent adjustment. The same would apply to spectacles brought in by someone other than the wearer or spectacles that have been stepped on, run over, or damaged in some other way. These frames must be brought back into standard alignment before additional adjustments should be attempted.

A general rule for standard alignment is to begin front-and-center and work to the back of the frame. In other words, start with the bridge, then work with the endpieces, and handle the temples last. Obviously, changes made in one part of a frame may influence the alignment in another part. Bending the bridge, for example, may change the relationship of the temples. Handling the bridge first, and the other parts in order, helps to eliminate having to go back and realign parts.

With the exception of only a few types of plastic material as explained in the previous chapter, adjustable plastic frames must almost always be heated to be aligned. Metal frames and parts do not require heating, except for metal parts that are covered with plastic.

This chapter is divided into sections on bringing plastic frames, metal frames, nose pads, and rimless frames into standard alignment. For instructional purposes, it is easier to consider each of these as separate and distinct types. In practice, however, there are a great variety of frames having characteristics that cross over. Some frames are hybrids of two or more types. This means that, in the end, the dispenser must often use the techniques learned in more than one section on a single frame.

It is advisable to first read the section on plastic frames before jumping to the metal or rimless sections. This is because the first section introduces terminology that is used but that is not as thoroughly explained in the later sections.

SECTION A: STANDARD ALIGNMENT OF PLASTIC FRAMES

HEATING THE FRAME

The most commonly used plastic frame material (cellulose acetate) should be heated for any alignment. Standard procedure for adjusting the frame should be followed, beginning with the bridge.

Only that area of the frame requiring adjustment should be heated to avoid the possibility of disturbing an aligned area by mistake. Frames may be heated using forced hot air, a "salt pan" containing heated, non-iodized table salt, or a pan containing heated small glass beads. The method of choice for heating frames is forced hot air.

Hot Salt or Glass Beads

Even though an explanation of how to use hot salt or glass beads is included, it should be noted that it is not recommended. Forced hot air is preferable because some of the newer frame materials are adversely affected by heating them using a salt pan. In addition, lens coatings may be damaged by the heat and abrasion of hot salt against the surface. Even if the coating appears undamaged after heating using a salt pan, the coating may not last as long. (It should be noted that lens coatings may be damaged if the lenses are heated excessively with hot air as well.) If lenses are returned in an unexpectedly short time because of a haziness or crazed surface when normal care has been exercised by the wearer, the difficulty may have begun right in the dispensary. (Surface crazing is microcracking that causes the lens surface to have the appearance of dried mud.) New dispensers have difficulty identifying frames or lenses that could be damaged with indiscriminate use of a salt pan. Therefore, if a salt pan is being used in the practice, it is safer to require novices to use a forced air warmer.

When using a salt pan, stir the salt to equalize the heat before inserting the frame. A wooden spoon is an excellent tool for this purpose; it does not get hot to the touch and can also be used to push the salt into mounds for heating specific frame parts.

Slide the frame into the salt just under the surface and as parallel to the surface as possible. The frame may bubble or distort if it is angled so that one portion is too close to the heating element (Figure 8.1). Gently moving the frame about while in the salt also helps to prevent this problem. If the frame is not moved, even cellulose acetate frames may acquire small indentations in the plastic surface. These small indentations will appear to dull a smooth, highly polished, jet-black frame. For this reason, some advise against using a salt pan for black frames.

Talcum powder may be mixed with the salt to prevent the salt from sticking to the frame and from lumping. Salt will also stick to a frame that has been cooled in cold water and again placed in the salt while still damp. For this reason, warm-air heating is preferable for a wet frame.

Figure 8.1 An example of a frame that has been overheated, resulting in bubbling of the plastic on the upper rim.

Figure 8.2 To heat the bridge area, first form the salt into a centrally located peak running across the pan, then draw the bridge through the peak of the salt mound.

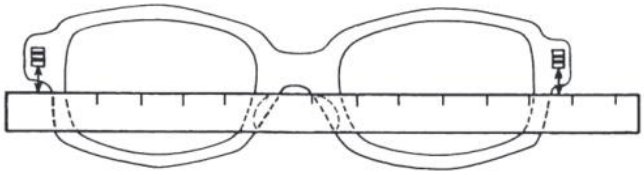


Figure 8.3 Checking for horizontal alignment. This frame shows proper alignment because the distance between ruler and endpiece reference point is equal on both sides.

BOX 8.1 Points to Remember in Heating Frames

With Hot Air

1. Heat only the portion of the frame to be worked on.
2. Rotate the frame in the heat. (This is especially important for warmers having heat coming from one direction only.)
3. Check the type of frame material. Some materials can stand more heat than others.

With Salt or Beads

1. Ask yourself, "Should this frame material or these lenses be subjected to salt or beads?" If there is any doubt, use hot air.
2. Always stir the salt (or glass beads) first.
3. Keep the area of the frame being heated parallel to the surface of the salt.
4. Keep the frame moving slowly.
5. Heat only the portion of the frame to be worked on.

Forced Hot Air

The method of choice for heating frames is forced hot air. When using hot air to heat a frame, move or rotate the frame to prevent overheating of one area and to ensure even heating of the different surfaces, especially if the hot air warmer only supplies air from one direction. The surface plastic of a frame will bubble if overheated by forced hot air on one side only. This may happen before the frame is hot enough to become pliable.

For a summary on heating frames, see Box 8.1.

THE BRIDGE

Since several things may be in error in relation to the bridge, the bridge itself is judged mainly by the effect it has on the plane of the lenses. Readjusting the lenses to their proper planes is accomplished by first heating the bridge area, then grasping the frame by the lens areas, and adjusting according to the correction desired.

When using a salt pan to heat the bridge, stir the salt in the pan and form it into a centrally located peak running across the pan. Place the frame in the pan, temples up, and draw the bridge through the peak of the salt mound. Repeat until the bridge is pliable enough to be bent (Figure 8.2).

When using hot air, concentrate the air stream on the bridge. This may be done with a cone attachment placed over the air exit or by partially closing the exit depending on the type of warming unit being used. Move the bridge through the hot air stream until it becomes pliable. Once the bridge is pliable, it can be adjusted as necessary to affect the desired correction.

The bridge can be out of alignment because one lens is pushed up or one lens is pushed back in relation to the other. If one lens is higher than the other, they are said to be out of *horizontal alignment.* If one lens appears to be farther forward or backward than the other, they are said to be out of *vertical alignment.*

Horizontal Alignment

It is not easy to check for horizontal alignment of a plastic frame because there are not always clear reference points. To check for horizontal alignment, place a ruler or straight edge across the back of the frame at the top of the pads, if any. If there are no pads, there may be a point where the sculptured shaping of the bridge area ends (this area serves as a nose pad). Both endpieces should be equidistant from the straight edge when it is aligned horizontally (Figure 8.3). A practiced eye may be more helpful than a ruler.

Rotated Lens

There are two common causes for a frame being out of horizontal alignment: a rotated lens and a skewed bridge. A lens rotated in the frame will cause the top of the eyewire to either hump up at the nasal bridge or one endpiece to appear upswept in shape. (See Figure 7.7 in the previous chapter.) To correct the problem, use lens rotating pliers. How this is done is explained in Chapter 7.

Skewed Bridge

When viewed from the front, a skewed bridge will cause one lens to appear higher than the other (Figure 8.4). This problem usually only happens after the glasses have been dispensed and something has happened to them.

To correct a skewed bridge, first heat the bridge, then grasp the front with an eyewire in each hand as shown in Figure 8.5. Force the eyewires in opposite directions until the tops of the eyewires are parallel. Of course, the lens must be in the frame for this procedure to succeed. When pressing the lenses in opposite directions, it is important that their frontal planes be kept parallel so that X-ing of the frame is not inadvertently introduced. X-ing will be described in more detail below.

Figure 8.4 An example of a skewed bridge. It should be noted that neither of the lenses shows any twisting. The error is manifested by one lens being higher than the other. (This photo shows the frame from the front. Figure 8.5, showing correcting the problem, is taken from the back of the frame.)

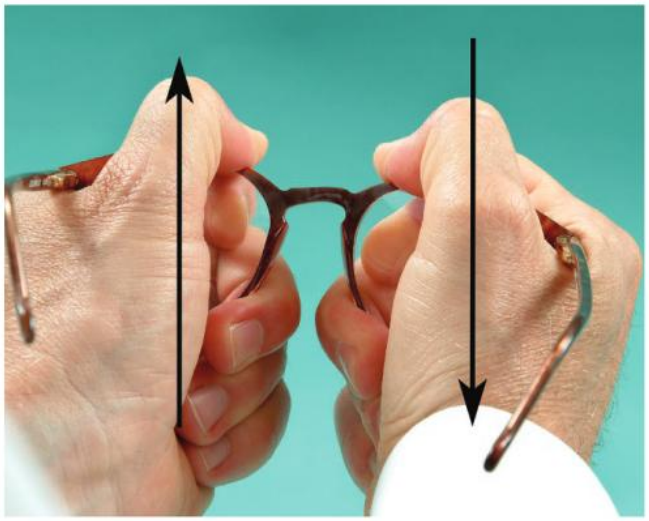


Figure 8.5 To correct for a skewed bridge, heat the bridge and force one side up and the other down. This is the same frame as shown in the previous figure, but the frame is now facing in the other direction. (Note which way the temples are pointing.)

Vertical Alignment (Four-Point Touch)

To check for vertical alignment, or *four-point touch*, place a ruler or straight edge so that its edge goes across the inside of the entire front of the spectacles below the nose pad area. Theoretically, the frame eyewire should touch at four points on the ruler (i.e., at each place where the ruler crosses the eyewire [Figure 8.6]). However, four-point touch is only expected in frames without face form. You may recall from Chapter 5 that the absence of face form is only appropriate in frames having a frame A + DBL equal to the wearer's interpupillary distance (PD).

Face Form

Face form, or *wraparound*, is when the frame front is just slightly rounded to the form of the face. Most frames are constructed with at least some face form. This is especially true of large frames and thick metal frames. Frames with face form will not conform to the four-point touch test but must be symmetrical nonetheless. The temporal sides of the eyewires should touch, and the nasal sides should be equidistant from the ruler (Figure 8.7).

Too much face form would be evident if the two nasal eyewires are a great distance from the ruler. In Figure 8.8, the frame front bows outward. If checking for four point touch, a ruler will either only touch on the two nasal eyewires or on the nasal and temporal eyewires of only one side of the frame front. This is called *negative face form*, or *anti-faceform*, and is not acceptable. (see Figure 8.8).

The remedy for either too much or too little face form is to alter the bridge. First warm the bridge until it is pliable, then grasp the frame by

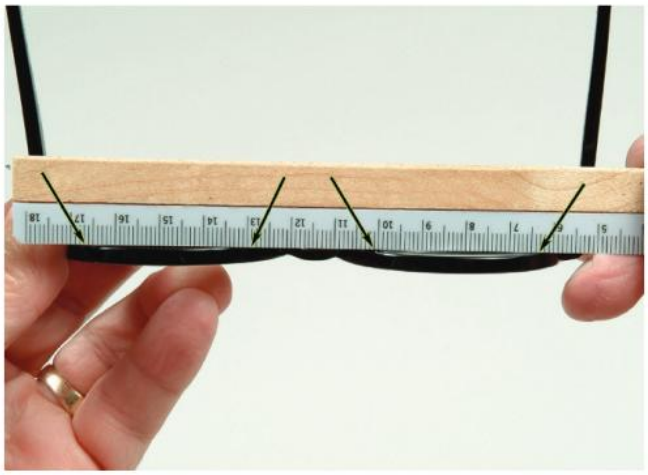


Figure 8.6 Checking for four-point touch. The frame eyewire touches at each place where the ruler crosses the eyewire. This indicates correct alignment when the frame PD equals the wearer's interpupillary distance (PD). In most instances the frame PD will be less than the wearer's PD, and face form will be required, as in Figure 8.7.

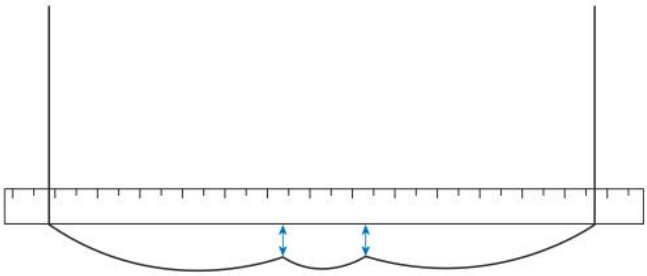


Figure 8.7 For those frames that will not or should not conform to a perfect four-point touch, the nasal sides of the eyewire should be equidistant from the ruler.

Figure 8.8 This is an example of a frame with negative face form. Negative face form is an inappropriate frame alignment.

Figure 8.9 As is often the case in dispensing, symmetry is important. To achieve a good bend when changing the face form of a frame, the glasses are grasped symmetrically, immediately adjacent to the bridge.

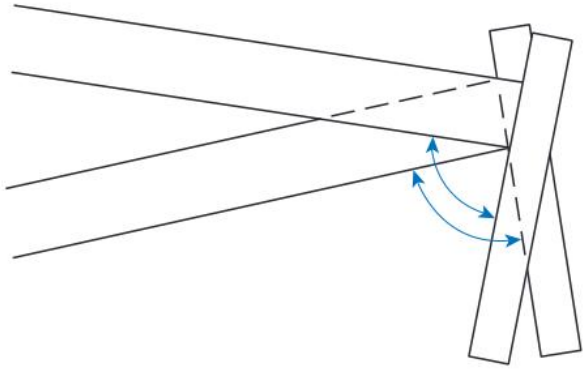


Figure 8.10 X-ing may be identified by the characteristic *X* the eyewires make with one another when viewed from the side.

the lenses and eyewires with thumbs on the inside and fingers on the outside. Bend the bridge by turning the lenses inward or outward (Figure 8.9).

X-ing

Another type of vertical misalignment occurs when the frame front is twisted so that the planes of the two lenses are out of coincidence with each other. This is called *X*-ing because the eyewires of the frame front form an X when viewed from the side (Figure 8.10). From below, the frame with X-ing appears as shown in Figure 8.11. X-ing is important because failure to find and correct X-ing will cause what may otherwise appear as mysterious problems in getting the frame correctly adjusted to the wearer.

Use the following procedure to check and correct for X-ing:

1. Look at the glasses from the bottom. Tilt the temples toward you until the back surfaces of both left and right lenses are just visible. When this occurs, the top and bottom rims of both lenses will also be visible.
2. Slowly tilt the temples away from you. Keep watching the left lens until the top rim of the left lens is *first* covered by the bottom left rim. Glance over to the right lens and see if the top right rim is also covered by the bottom right rim. If right top rim is *not* covered (as shown in Figure 8.11), then X-ing is present. Here's the catch. If the right top rim is covered, there might still be X-ing present!
3. Start Step 2 over again. This time keep watching the *right* side until the top rim of the right lens is *first* covered by the right top rim. Now glance over to the left side. Is the left top rim covered by the left bottom rim? If so, no X-ing is present. However, sometimes the left top rim will *not* be covered, even though in Step 2, all appeared to be well.
4. If X-ing is present as discovered in either Steps 2 or 3, correct the X-ing by grasping the eyewires as shown in Figure 8.12. Rotate

Figure 8.11 This is how a frame with X-ing appears when viewed from below.

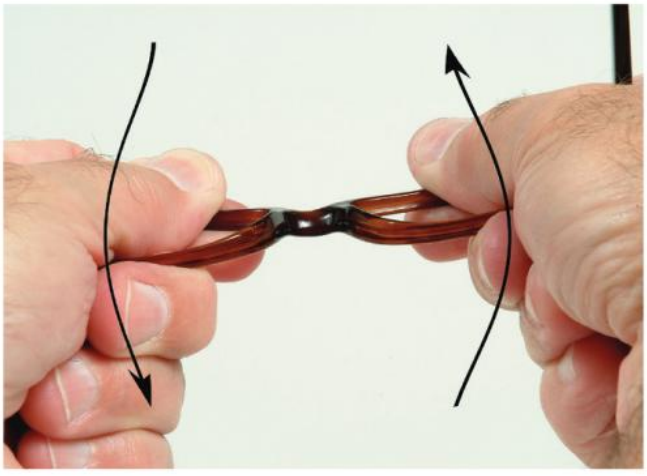


Figure 8.12 In grasping the frame to correct an X-ing error, the wrists move in opposite directions.

the hands in opposing directions until the planes of the lenses are parallel.

5. Keep rechecking Steps 2 and 3 and making corrections until both Steps 2 and 3 show that X-ing is no longer present.

Because alignment of the front of the frame affects the rest of the frame, X-ing causes the temples to be out of line with each other. In other words, the temples will not be parallel with each other when viewed from the side. However, X-ing it is not the only reason why temples may be out of line with each other. Whenever the temples do not appear parallel, the frame should first be examined for X-ing before other methods of realigning the temples are tried. Temple alignment is explained shortly.

Variant Planes

Another form of vertical misalignment is when the lens planes are *variant*, or *out of coplanar alignment*. In this situation, the lens planes are parallel, but one lens is farther forward than the other (Figure 8.13). This error usually becomes apparent when the four-point touch test is used, although it may easily be otherwise overlooked.

To correct a frame with lenses out of coplanar alignment, first heat the bridge and grasp the frame in the manner shown in Figure 8.9, just as would be done in correcting a frame having too much face form. This time, however, push the entire eyewire away from you on one side, and pull it toward you on the other side, all the while keeping both lens planes parallel to each other.

THE TEMPLES

After horizontal and vertical standard alignment adjustments have been made to the bridge and lens rims, the third area considered in truing a frame is the temple area. The open temple spread is checked first because adjustments may involve the endpieces. After this, temple parallelism is considered followed by alignment of the temple ends. Finally, the temple-fold angle is corrected.

Open Temple Spread (Let-Back)

The *open temple spread*, or *let-back*, is that angle that each open temple forms in relationship to the frame front. To afford a true picture of the temple spread initially, the temple shafts must be straight. Before going further, stop and straighten the temple shafts. Any curve to the temple shaft should be eliminated by heating the temple and straightening it with the hands.

Typically, most wearers require temples to be opened outward to 94–95 degrees. However, unless the dispenser can recall the head and face structure of the wearer, it may not be desirable to spread the temples to more than 90 degrees when the glasses are initially received from the optical laboratory. Otherwise, if the wearer's head is narrow, opening the temples larger than 90 degrees will need to be undone, creating more work than necessary.

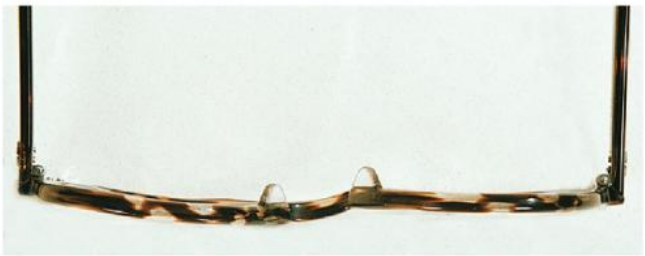


Figure 8.13 Here is an example of lens planes that are variant, or out of coplanar alignment. In spite of the improperly bent bridge, the lenses remain parallel to one another.

Temples Spread Too Far

Temples flaring out more than 95 degrees are spread too far for standard alignment (Figure 8.14). There are several methods for correcting this problem, but all involve the same principle: The endpiece must be heated and bent inward so that the temple will not be able to open out as far.

With the temple spread to the wide-open position, begin the procedure by heating the desired area. Having the temple fully spread makes it easier to tell when the endpiece has been bent enough. This is because it is possible to see the extent to which the temple is being forced inward. If the frame has a hidden hinge, take care to avoid bumping or knocking the temple because this can loosen it.

The following methods can be used for endpiece adjustment to reduce temple spread:

1. *Using the thumb*—While the endpiece is hot, hold the frame by the eyewire, and push on the endpiece with the thumb (Figure 8.15). It

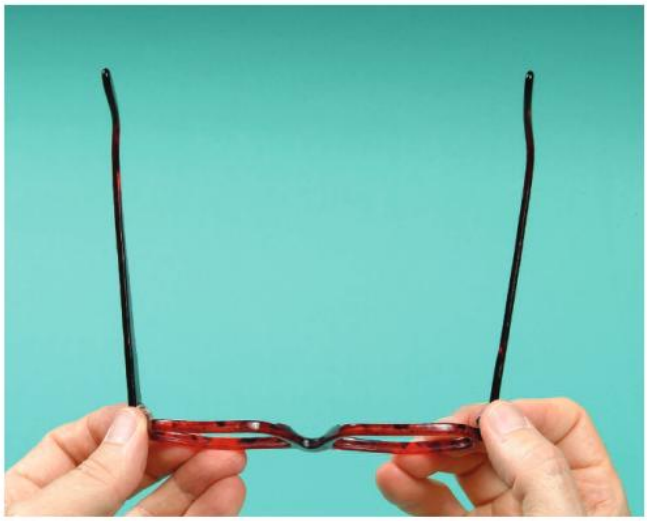


Figure 8.14 The temples on this frame are spread too far for a frame in proper alignment. The spread should be decreased until the temple and the frame front are at a 94- to 95-degree angle to each other.

Figure 8.15 One method of decreasing temple spread involves holding the frame by the lens and eyewire while pushing the endpiece inward with the thumb.

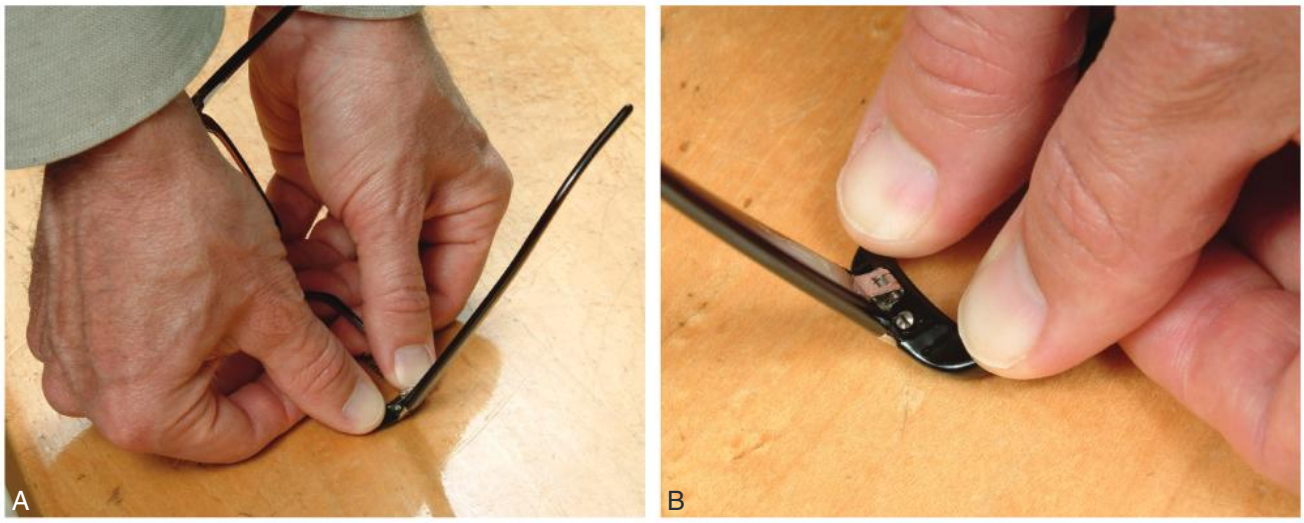


Figure 8.16 One of the easiest and most successful methods of reducing temple spread is pressing the endpiece against a flat surface. **A** and **B** show two views of how this is done.

is prudent to place a cloth between the thumb and the frame front to prevent burning the skin, especially if there is a metal shield on the front.

2. *Using a flat surface*—Heat the endpiece and grasp the eyewire and lens with both hands. Press the endpiece of the frame down on a flat surface to force the endpiece inward (Figure 8.16, *A* and *B*). Avoid irregular surfaces or foreign matter such as salt grains, which may mar the frame.

   It is helpful to stand up and position yourself with your shoulders above the frame so that you can lean your weight onto the frame and place more pressure on the endpiece.

   Often the corner of the lens may pop out when pressing the endpiece against a flat surface. If this happens, turn the frame around and push the corner of the lens with the thumbs while supporting the eyewire from behind with the fingers. This will pop the lens back into the frame. This may occur several times during the procedure.
3. *Bend eyewire and endpiece*—When the endpiece will not bend enough using the above two methods, take the lens out of the frame. With the frame empty, the eyewires and endpieces may be bent inward more easily (Figure 8.17). After reshaping the frame, reinsert the lens.
4. *Bend the butt portion of the temple*—If none of the previous three methods proves successful, this method can be used. It is usually only employed with older frames and as a last resort because the cosmetic appearance of the frame suffers. (Before doing this, check to see if adding more face form to the frame would be appropriate. This will also decrease the temple spread.)

   Heat the temple, and grasp the butt end of the temple with half-padded pliers as near to the hinge as possible. (Half-padded pliers are shown in Figure 8.18.) Then, grasp the temple near the pliers with the free hand and bend the temple inward (Figure 8.19).
5. *Sink the hidden hinge deeper into the frame front*—In cellulose acetate frames with hidden hinges, the temple spread can be reduced by sinking the front hinge slightly deeper into the plastic. This is done by removing the temple and heating the hidden hinge with a soldering iron or a Hot Fingers unit. It does not take very much depth change to significantly decrease the temple spread. (For more on how to do this, see the section on Hidden Hinges in Chapter 10.)

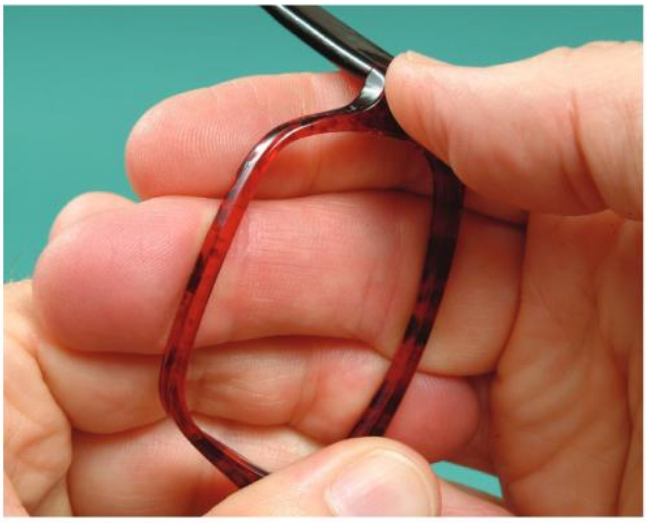


Figure 8.17 After having removed the lens, brace both eyewires with the middle and forefinger. Press the endpiece with the thumb to decrease the temple spread. Concentrate the bend as close to the endpiece as possible.

Temples Not Spread Enough

Occasionally, the temples are not spread enough after the lenses have been inserted and the bridge area straightened. There are at least three things that may be done to correct the problem when this occurs. They are as follows:

1. *The lens may not be completely in the frame at the endpiece.* Check to see if the lens is in place. If not, press the lens back into the groove.

Figure 8.18 Half-padded pliers hold the frame securely. The nylon-padded jaw prevents the frame from being marred by that jaw of the pliers. The unpadded jaw may be flat or rounded.

Figure 8.19 If no other method proves successful, it is possible to bring the temples in by grasping the temple butt with half-padded pliers and bending the temple with a free hand (shown from above).

2. *The endpiece needs to be bent outward.* Heat the endpiece area, and pull the endpiece outward with the fingers while supporting the lens with the thumbs (Figure 8.20). Never pull on the temple because this will only loosen it and will not get to the root of the problem.
3. *File the butt end of the temple.* When neither of the previous methods work, it may be necessary to file the temple. This may occur when the temples come inward considerably, as when lenses with steep front curves are used. The reason may be the additional curve added to the frame front because the eyewires are shaped to conform to the curved lenses.

To correct this problem, file the end of the temple at the hinge area where it contacts the front of the frame using a fairly rough file (Figure 8.21). It is extremely important to note that filing for this purpose is done only on the temple—never on the frame front. Individual replacement temples of identical manufacture will often fit at varying angles on the same front. If the front were filed instead of the temple, the result might be an unusually large temple spread if the temples were replaced.

To file the temple, brace the glasses against something solid or hold the frame with the temple folded and the knuckle of the index finger over the edge of a table top for support (Figure 8.22). File the end evenly and uniformly. Periodically, open the temple fully so that its abutment against the endpiece may be observed. Note whether or not the end of the temple is fully touching the endpiece.

One common filing error results in a gap at either the top or bottom of the butt end area of contact with the endpiece (Figure 8.23). A second common error occurs if the temple is filed too much on the inside, leaving only a small area of contact between the temple and the frame front (Figure 8.24). The first error is particularly undesirable cosmetically. Both errors cause difficulty after a period of wear because the area under concentrated pressure eventually gives way and allows the temple to flare out too far, loosening the glasses.

It is usually not possible to file very far before hitting what appears to be a metal reinforcing piece, which is actually a part of the hinge itself. It does not damage or weaken the frame to file on this piece; in fact, it is unavoidable if much filing is required.

4. *Bend the temple outward.* If none of the above solutions are possible, as a last resort bend the temple outward at a location approximately ¾-inch down the temple from the endpiece. This is usually done using one hand to use half-padded pliers to hold the butt end of the temple and the other hand to bend to temple outward, similar to the bend shown in Figure 8.19.

For a summary of temple spread problems and their solutions, see Table 8.1.

Temple Parallelism

For frames to be in standard alignment, the temples need to be parallel to one another when viewed from the side. One temple should not be angled down more than the other. When looking at the glasses from the side, the equality of the angles that the temples make with the frame front will determine temple parallelism. This angle is called the *pantoscopic angle*. In standard alignment, the pantoscopic angle is the angle the frame front deviates from the vertical when the glasses are held with the temples horizontal. When fitting the frame to the wearer, the pantoscopic angle refers to the angle formed between the frontal plane of the face and the plane of the frame front when the glasses are being worn. So the degrees of pantoscopic angle will depend upon whether one is speaking of the pantoscopic angle of standard alignment or the pantoscopic angle the frame front makes as worn. (How high or low the ears are situated on the head relative to the eyes will change the amount of pantoscopic angle when the frame is being worn.)

Viewing the frames from the side when worn, the angle is designated as *pantoscopic* when the lower rims of the frame front are closer to the plane of the face than are the upper rims. A proper pantoscopic angle may approximately range from as little as 4 degrees up to as much as 18 degrees or more. If the glasses were to be adjusted so that the lower rims are tilted *outward* from the face, the glasses are said to have *retroscopic* instead of *pantoscopic* tilt. Retroscopic tilt is seldom ever appropriate.

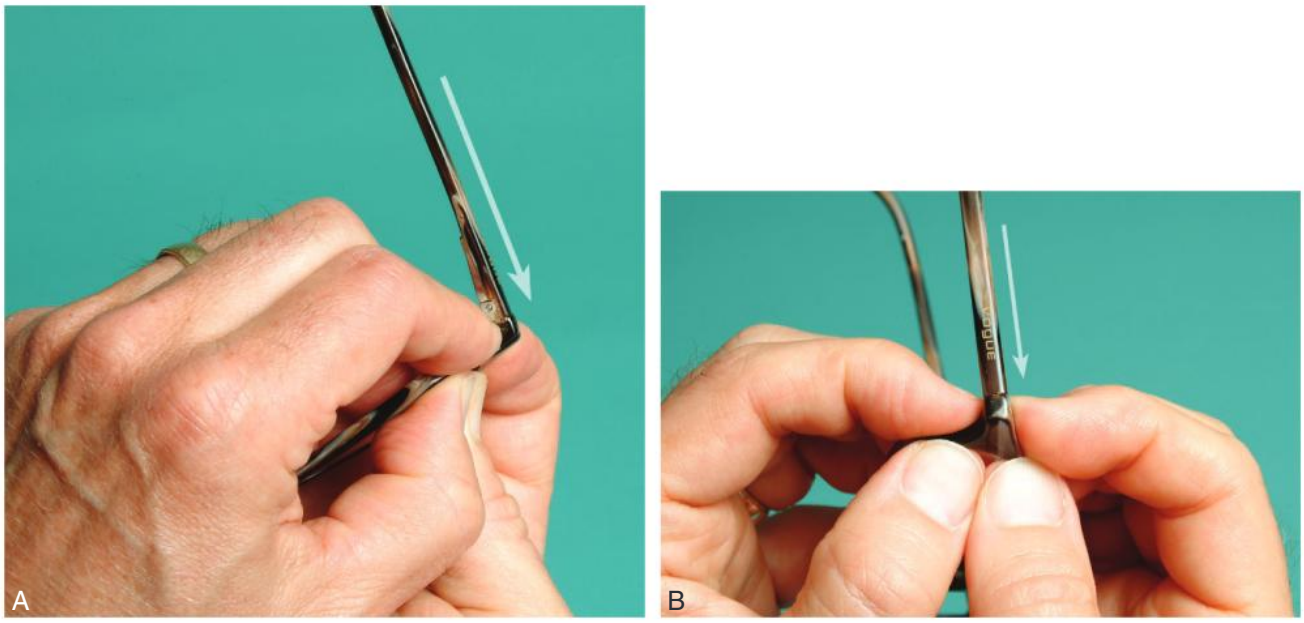


Figure 8.20 To spread the temples, heat the endpiece and pull back with the fingers while pressing with the thumbs. (This is shown from two different views in **A** and **B.**) This should cause the angle of temple spread to increase. If, by chance, the lens was not completely in the temporal groove of the frame, it could be a major cause of the temple being insufficiently spread. If the lens is not in the groove, this action should also cause the lens to pop back into place.

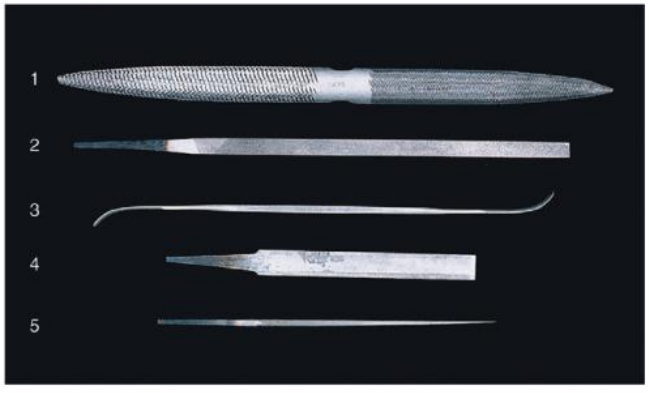


Figure 8.21 Standard files used in dispensing. From *top* to *bottom*: *1,* Zyl file—used to file plastic parts of a frame. Although both ends are coarse, one is less coarse than the other for variations in speed of filing. *2,* Pillar file—finer than the zyl file, this file is often used to file metal parts of a frame. *3,* Riffler file—this spoon-shaped file is good for getting at small, hard-to-reach areas. It is used with thumb or finger in the arc of the "spoon." *4,* Slotting file—used for reslotting screws or making a slot where none previously existed. *5,* Rat-tail file—for classic-type rimless mountings, this file was used to reduce lens thickness in an area to allow for proper lens strap grasp. It is also used to smooth the inside of a drilled lens hole.

Figure 8.22 Even though using a specially designed bench brace is the method of choice, a frame may be successfully held for filing by bracing one knuckle over the edge of a table.

To test whether the temples are parallel, position the glasses *upside-down* on a flat surface with the temples open. Note whether both temples sit flat or if one temple is not touching the flat surface. If it is difficult to tell, first touch one temple and then the other to see if the frame wobbles back and forth or if it sits solidly. This procedure is known as the *flat surface touch test* (Figure 8.25). If the frame wobbles, it needs correction or it will sit on the face at an angle.

A common mistake is to check for temple parallelism with the glasses placed on the table right side up instead of upside down. If this is done and the bent-down portion of one temple is bent down even the slightest bit more than the other, or if one temple bend is located even the least bit farther forward than the other bend, the flat surface touch

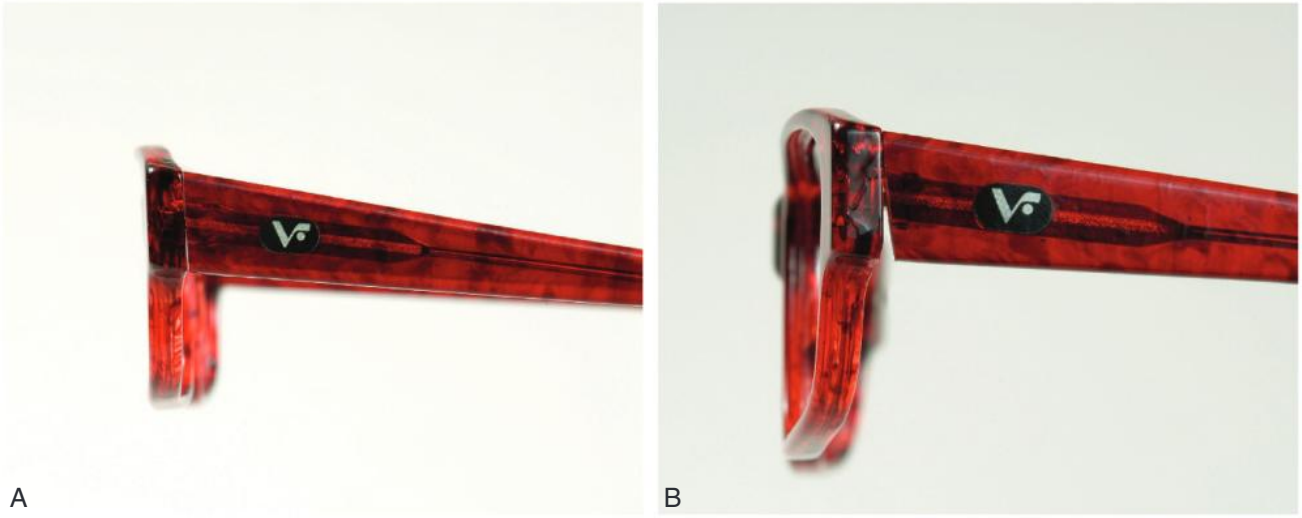


Figure 8.23 The frame pictured in **A** shows the proper abutment between temple and frame front, whereas the frame in **B** is the result of uneven or hurried filings.

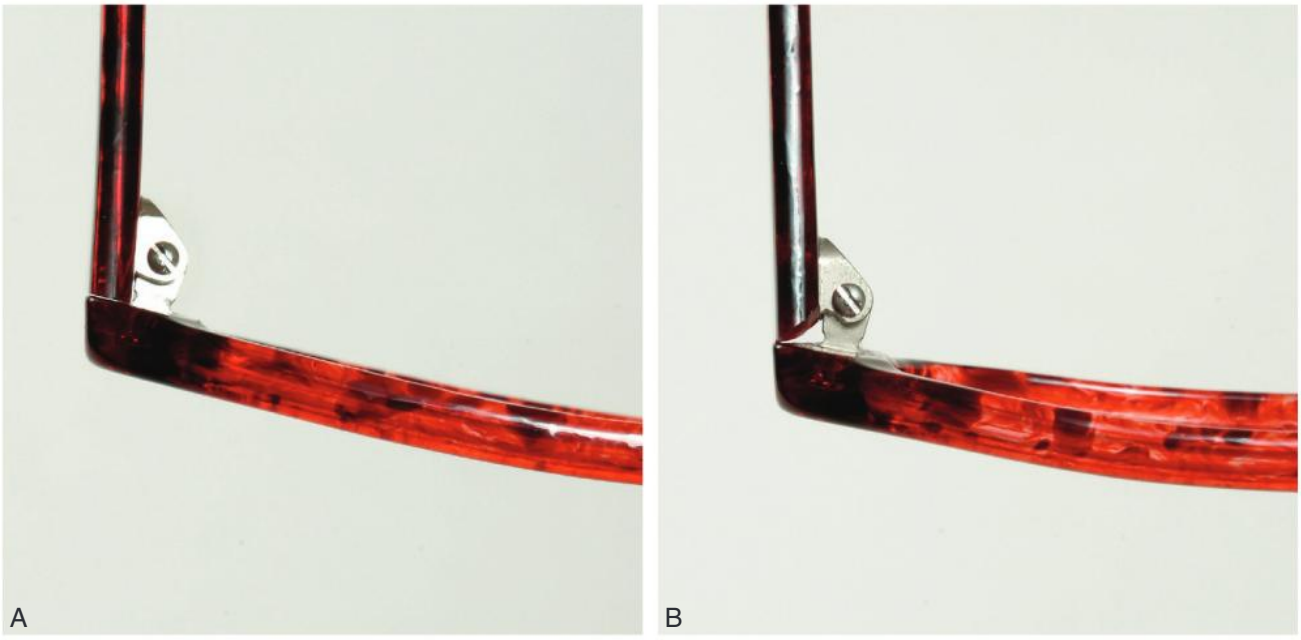


Figure 8.24 Viewed from the top, the frame in **A** shows how temple and front should abut. The improperly filed temple in **B** will not hold alignment. Because so much force is on such a small area, within a short period of time, the plastic will be compressed, allowing the temple to open too far.

TABLE 8.1 Plastic Frame Temple Spread Problems and Their Solutions

Problem	Solution
Temples spread too much	1. Heat the endpiece, and press it inward with the thumb. 2. Heat the endpiece, and press it against a table top. 3. Remove the lens, and bend the endpiece and the eyewire near the endpiece. Reinsert the lens. 4. When the frame is old or will not respond to the above methods, grasp the temple butt with half-padded pliers and bend the temple as close to the pliers as possible. 5. Sink the hidden hinge deeper into the frame front using a Hot Fingers unit or soldering iron.
Temples spread too little	1. Check to see if the lens is in the temporal groove of the frame. If not, heat and press the lens into the groove. 2. Bend the endpiece outward. 3. File the temple where it abuts with the front. 4. If none of the above are possible, bend the temple outward at a location approximately ¾-inch down the temple from the endpiece.

Figure 8.25 Testing for parallelism (equality of pantoscopic angles) using the flat surface touch test.

test for temple parallelism will not work. The frames should be upside-down on the table.

The second way to test for temple parallelism is to view the temples from the side. One temple should hide the other from view when looking from the side. This requires practice to develop an eye for accuracy. However, it will allow one to check for straightness of the temples and equality of the temple bend placement and temple end angles at the same time.

There are five possible sources for incorrect temple parallelism:

1. Incorrect temple parallelism will result if the *endpiece* is not straight. This can happen because:
   a. The lens is not inserted into the frame squarely at the endpiece area. Check this first. It will cause the overall temple angle to be affected. If the lens is only slightly out of the eyewire, heat that area of the frame and press the lens back into the groove. It is usually not necessary to remove and reinsert the lens.
   b. The endpiece is simply angled improperly. If the endpiece was bent upon insertion of the lens, heat the endpiece area. Use the fingers, protected by a lab towel, to bend the endpiece.
2. Another cause of error could be a bend in the *temple shaft* itself (Figure 8.26). This should also be checked early on as it can easily occur. This situation is easily solved by heating and straightening the temple shaft.
3. It is even possible for temples to stray from parallel because the bridge of the frame has been twisted. This problem should have been discovered earlier in the alignment process and is called X-ing as described previously.
4. If a frame has a hidden hinge that is loose, this makes the temple loose and will cause that temple to be out of parallelism. (For more on this, refer to the section called *Repairing the Hinges* in Chapter 10.)

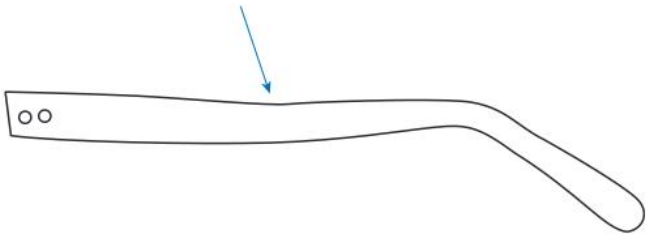


Figure 8.26 A bend in the shaft of one temple may cause the glasses to wobble when placed on a flat surface with the temples open.

If the frame holds the hinges in place using rivets, the problem might be that of loosened or broken *hinge rivets*. Currently, this is unlikely to be the problem since frames are seldom made using rivets. Some frames are made with a decorative shield and look like they are made with rivets, but they are not. If the frame does have rivets, they are the likely problem if the temple seems wobbly even after the hinge screw has been fully tightened. (See Chapter 10.)

5. After the above problems have been ruled out, the *hinges* themselves are likely at fault and may require straightening. Go on to the next section for how to solve the problem.

Bending the Hinge to Solve for Temple Nonparallelism

Using Only the Hands. To use only the hands to change the angle of the temple, close the temple a few degrees from the completely opened position. Grasp the frame front near the endpiece with one hand. Angle the temple by grasping it with the other hand near the butt area, and force it up or down (Figure 8.27). This is probably the most common method for changing the temple's pantoscopic angle, but it is certainly not the best. Not only is it not always possible to change the pantoscopic angle using the hands only and no tools, but it is also more likely to damage the frame. Here is a better tool-based method to change the angle:

Using Endpiece Angling Pliers. If the endpiece has enough space, it can be grasped with half-padded pliers. The padded jaw of the plier should be in the front and the unpadded jaw in the back. These serve as holding pliers. Use a second pair of *angling pliers* (Figure 8.28) to grip the hinge by the top and bottom of the screw. (Note that the endpiece angling plier handles are held parallel to the frame front.) Grip the top and bottom of the hinge. Do not grip the top and bottom of the temple itself as the pliers will mar the temples of the frame. Angle the hinge by twisting the pliers until one temple is level with the other (Figure 8.29). If the temple is opened completely and tight up against the endpiece of the frame front, the temple is prevented from being angled either upward or downward. To keep this from happening, the temple should be closed very slightly so that the butt end of the temple is not in contact with the endpiece. This way the temple is free to be angled upward or downward.

If there is not enough space to grasp the endpiece with half-padded pliers to hold the frame (which is often the case), use the angling pliers alone, and hold the frame front with the other hand to change the pantoscopic angle. In practice, this is the most common method used.

Of Special Note: The frame should *not* be heated when any of the pantoscopic angling operations are performed. The bend should be to the hinge, not to the plastic. Heating will soften the plastic, cause the bend location to be misplaced, and likely result in loosening of the hinge!

For a summary of possible sources for unevenness of pantoscopic angles, see Box 8.2.

Aligning the Temple Ends

Proceeding toward the back of the frame, the next area to be aligned is the bent-down portion of the temple—the temple ends. When the temple ends are to be bent down, a good standard alignment demands that both ends of both temples be bent down equally as viewed from the side (Figure 8.30).

Both temple ends should also be bent inward very slightly (Figure 8.31) because the average head has this conformation. If heating is done with a salt pan, it is important that the ends of the temples be held in the pan parallel to the surface (Figure 8.32, *A*) and not perpendicular (see Figure 8.32, *B*). If the temple end is inserted perpendicularly into the salt, the tip is usually overheated. (It is best to use hot air instead.)

Figure 8.27 This photo shows a commonly used method for changing the pantoscopic angle of the temple. This will not be successful if the temple is fully opened. If it is, there is no space to angle the temple. The butt of the temple must not be quite in contact with the frame front.

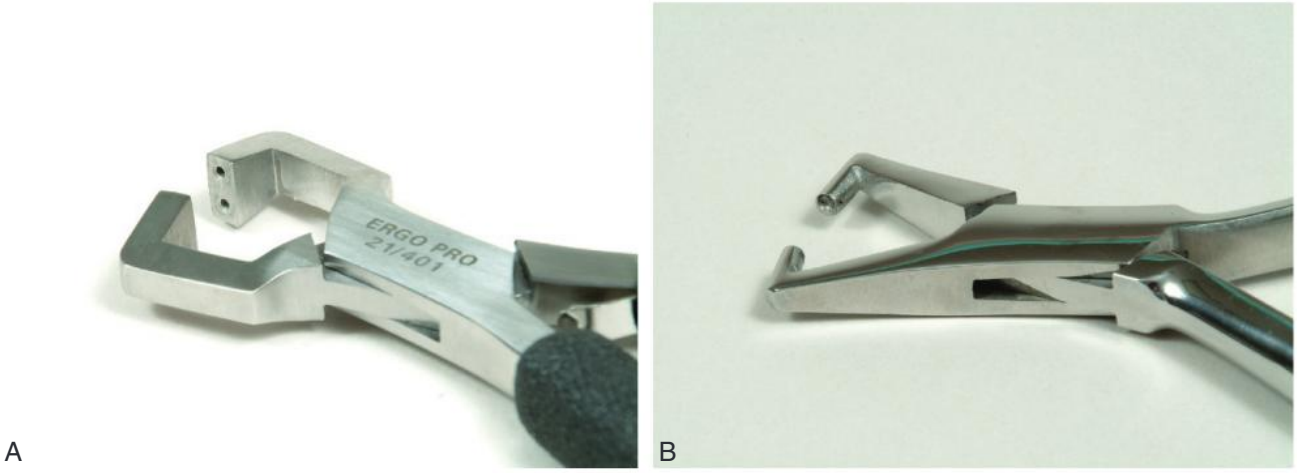


Figure 8.28 Angling pliers. Traditional endpiece angling pliers are shown in **A.** Note the indentations on the inside of the jaws used to grip the screw. The flat section of the jaws are excellent for gripping the top and bottom of the hinge—particularly spring hinges. It is very common to do this bend using only endpiece angling pliers. Instead of half-padded pliers to hold the frame front, the front is hand held. If there is simply not enough room to use a traditional endpiece angling plier, a modified, narrower version as shown in **B** can be used.

Temple-Fold Angle

The final alignment step is to fold the temples to the closed position and observe the angle formed as the temples cross. The temples should fold so that they are parallel to one another or form slight angles from parallel. These angles should be symmetrical and should cross each other exactly in the center of the frame in line with the center of the bridge. Proper adjustment to this configuration permits the glasses to easily fit into a standard glasses case.

There are two common methods of changing the temple-fold angle:

1. In the first method, the frame front is held with one hand. Angling pliers grasp the top and bottom of the screw and hinge. Pliers are

Figure 8.29 This technique for changing the pantoscopic angle is excellent but cannot always be carried out because of endpiece design. With wraparound endpieces, the endpiece can be grasped at another location.

BOX 8.2 Possible Problems If Pantoscopic Angles Are Uneven: The Frame Fails the Four-Point Touch Test

1. The lens is not fully in the temporal frame groove.
2. There is a bend in the endpiece.
3. The temple is bent along the shaft.
4. The frame has a twisted bridge (X-ing).
5. A hinge is loose or broken.
6. The hinge is bent or needs to be bent.

Figure 8.30 In this photo, the temple ends are not bent down equally. Standard alignment requires that both temple ends be bent downward at the same angle.

Figure 8.31 The ends of temples should be bent inward slightly to conform to the average head shape. The inward bend should be symmetrical, not like the example shown in which the left earpiece is bent farther inward than the right earpiece.

held perpendicular to the frame front (Figure 8.33). Since the hinge being bent is metal, heat should not be used.

2. The second method of angling the temple fold uses *finger-piece pliers*. These pliers have jaws that are parallel and have space between the jaws when fully closed (Figure 8.34). They are also referred to as *Fits-U* pliers. These pliers were originally designed for adjusting the old finger-piece mountings but are also excellent for adjusting the temple-fold angle. With the temple folded, the pliers are held parallel to the endpiece hinge screw so that the hinge is grasped on both sides (Figure 8.35). While the frame front is held with the one hand, the hinge is angled until it reaches the proper position (Figure 8.36) with the other hand.

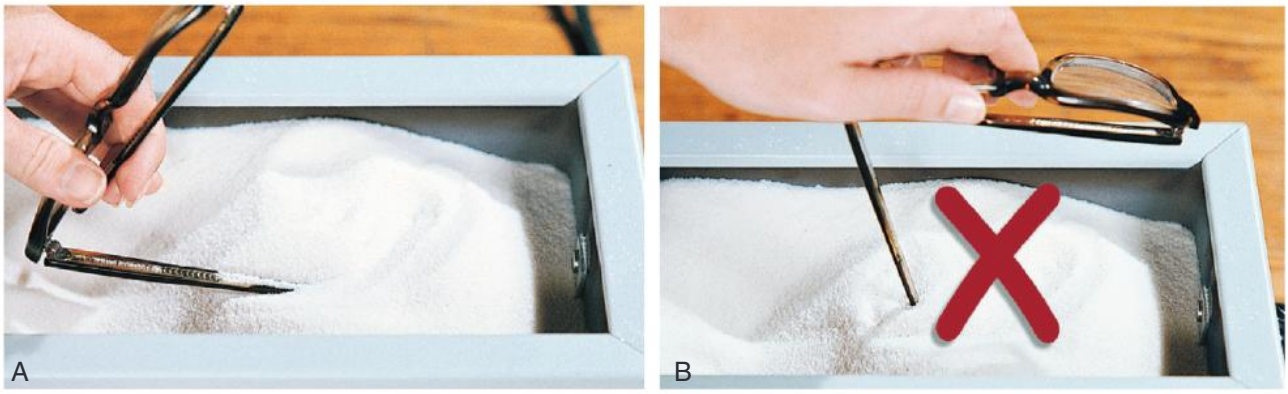


Figure 8.32 In heating the ends of the temples, it is important that they be held in the salt parallel to the surface as shown in **A.** Sticking the temple end perpendicularly into a salt pan as shown in **B** often results in overheating the tip and should be avoided.

Figure 8.33 Changing the temple-fold angle using a pair of angling pliers. The pliers should grasp only the top and bottom of the hinge—not the top and bottom of the temple. Grasping the top and bottom of the temple will damage the temple.

Some dispensers are afraid that changing the temple-fold angle will undo their previous four-point touch and destroy temple parallelism. For this reason, some skip the temple-fold angle entirely. Do not skip the temple-fold alignment! These two bends that take place in the hinge are at different rotational angles. (Notice the difference in how the angling pliers are held in Figures 8.29 and 8.33.) If there is any change in the pantoscopic angle, it is very minor and easily corrected.

Changing the temple-fold angle by simply bending the temple with the hands does not work as successfully as using pliers in the techniques described above. Using hands alone, without pliers, may cause the temple to split at the hinge.

When the temple-fold angles are complete, the temple tips should not rub against the lenses or they will scratch them. It is better to have less temple-fold angle than to scratch the lenses.

Check to see that the temple-fold angle will permit the glasses to fit into the intended glasses case.

For an overall summary of steps to follow in standard alignment, see Box 8.3.

Figure 8.34 Finger-piece pliers were originally designed for adjusting the old finger-piece mountings. These pliers are an excellent tool for adjusting the temple-fold angle.

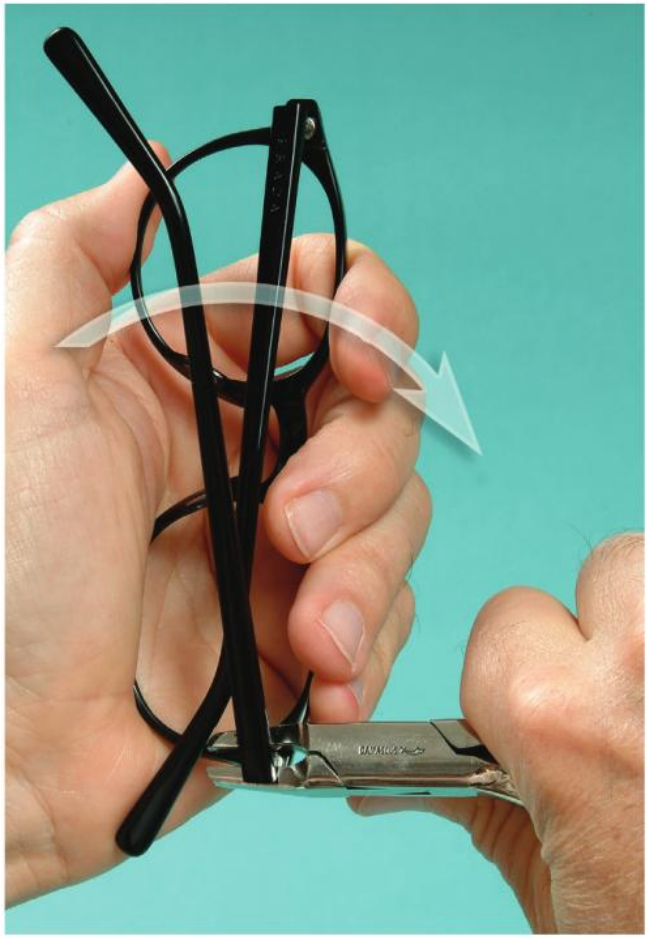


Figure 8.35 With the temple folded, finger-piece pliers are held parallel to the endpiece hinge screw so that the hinge is grasped on both sides.

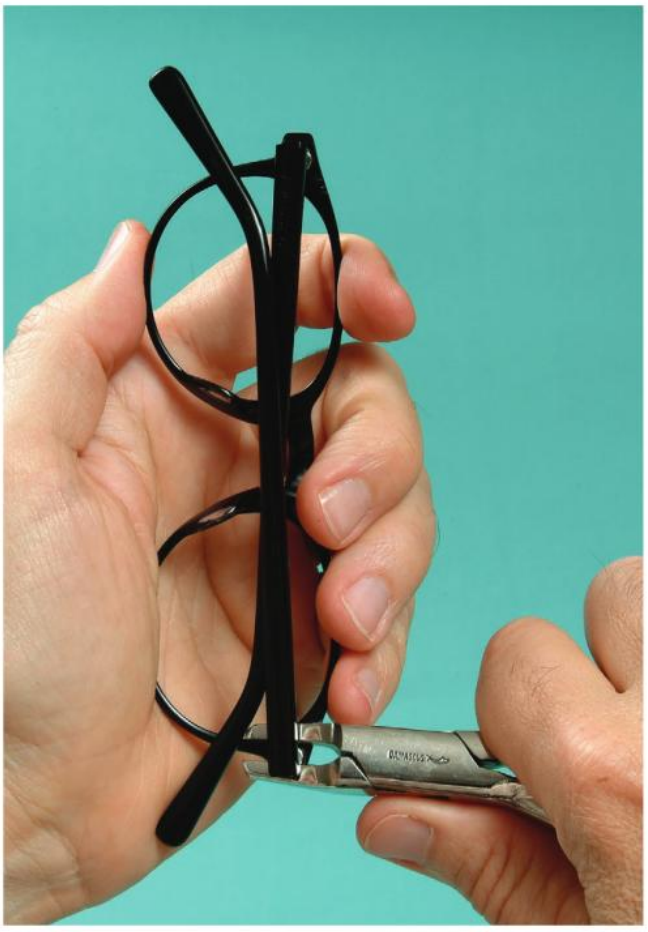


Figure 8.36 While the frame is held with one hand, the hinge is angled until it reaches the proper position as shown with the other hand.

BOX 8.3 Steps in Standard Alignment or Truing of Frames

Step 1. Horizontal bridge alignment
- a. Check for a rotated lens.
- b. Check for a skewed bridge.

Step 2. Vertical bridge alignment (four-point touch)
- a. Check for X-ing.
- b. Check for variant planes (or lenses out of coplanar alignment).

Step 3. Open temple alignment
- a. Check the temples for straightness of shaft.
- b. Check for angles of the temples when fully opened for symmetry.

Step 4. Temple parallelism (flat surface touch test)
- a. Check for bent endpiece.
- b. Check for loose hinge.
- c. Check for bend in the temple shaft.
- d. If none of the above is at fault, the hinge is to be bent.

Step 5. Alignment of the bent-down portion of the temple
- a. Check for equality of downward bend.
- b. Check for equality of inward bend.

Step 6. Temple-fold angle
- a. Check for central crossing of the temple shafts when folded.
- b. Check for a fold that permits the insertion of the spectacles into a standard case.

SECTION B: STANDARD ALIGNMENT OF METAL FRAMES

Metal frames are aligned according to the same principles as plastic frames and, when in standard alignment, should meet approximately the same standards as well. The primary difference lies in the methods of manipulation used to bring the frame into alignment and the presence of adjustable nose pads.

Metal frames require heating only in those places where plastic coats the metal. All other bends are done "cold."

Pliers are used for the majority of adjustments. Since the pressure of metal jaws may mar or disfigure the finished surface of the frames, it is essential to use padded pliers or to cushion at least one jaw of non-padded pliers by attaching friction or adhesive tape to it.

The order of procedure for aligning metal frames is the same as that used for plastic frames, beginning with the bridge.

THE BRIDGE

As with plastic frames, the planes of the lenses are observed to determine bridge alignment as it relates to overall vertical and horizontal alignment.

Horizontal Alignment

To check for horizontal alignment of a metal frame, place a ruler or straight edge across the front of the frame at the point of attachment of the pad arms. In most frames, the endpieces will be considerably higher than the level of the pad arms, making the horizontal alignment judgment difficult. The endpieces should be equidistant from the ruler.

Rotated Lens

For metal frames, like plastic, there are two common causes for a frame being out of horizontal alignment. The first is a rotated lens, a condition characterized by a nasal or temporal upsweep in one lens causing the tops of the lenses to be out of parallelism. To correct for a rotated lens in a metal frame, loosen the eyewire screw, and turn the lens until it aligns correctly with its partner; then, retighten the screw.

Skewed Bridge

The second cause of horizontal misalignment is a skewed bridge in which case both lenses are oriented identically but one lens is somewhat higher than the other. Correcting a metal frame with a skewed bridge can be difficult, depending on the bridge design.

To correct bridge skewing with out pliers and only using the hands, grasp the frame front as was shown in Figure 8.5 for a plastic frame. As with plastic frames, pull upward on the side of the frame that is lower, and downward on the side of the frame that is higher. This will force the eyewires in opposite directions until the two sides are level. Much care must be exercised with this procedure because it is being carried out on a metal frame with the lenses in place increasing the risk for chipping a lens.

Horizontal skew cannot always be corrected using pliers because of bridge construction. Metal frames of a bridge construction similar to the rimless variety may be altered as described in the section on rimless eyewear.

Vertical Alignment (Four-Point Touch)

As when performing the four-point touch test with plastic frames, a ruler or straight edge is necessary to determine whether or not the frame is in alignment. Metal frame construction is so varied, however, that establishing a four-point touch when straddling the inner parts of the frame eyewires is more often impossible than possible. The test is used to analyze the symmetry of the frame front.

Face Form

Metal frames are usually designed with face form, especially in the larger eye sizes. Some very stout metal frames are not intended to meet the literal requirements of the four-point touch test and cannot be adjusted to do so. When checking vertical alignment, there are two questions to keep in mind:

1. Does the frame have a four-point touch or a face-form curve?
2. If the frame has face form, are the two nasal eyewires equidistant from the ruler or is one farther from it than the other?

Either pliers or hands may be used to change the degree of face form in a metal frame. If using pliers, use two pairs to grip the bridge near each eyewire. Rotate the pliers in opposite directions to each other to either increase or decrease the bridge curvature (Figure 8.37). The jaws of both pairs of pliers should be padded to prevent marking the frame.

Frames with reinforcing bars at the bridge do not lend themselves readily to the application of pliers. Most metal bridges may be altered by grasping the lenses and eyewires between the thumbs and forefingers and carefully bending the bridge (Figure 8.38). Undue stress at the

Figure 8.37 These double-padded pliers are rotated in opposite directions to either increase the bridge curvature (add face form) or decrease it. Pliers' jaws that come in contact with metal, especially the outer side of a metal frame, should be padded to avoid marring the frame finish.

Figure 8.38 This is how the hands are held to either change the face form of a metal frame or to remove X-ing. Care must be taken because undue stress at the lens/eyewire area may result in chipping of the lens edge.

lens/eyewire area must be avoided because it may result in flaking (chipping) the edge of the lens.

X-ing

The misalignment known as X-ing is exactly the same in metal frames as in plastic frames and can be discovered by the same means. It is advisable to review the exact procedures as outlined for X-ing in Section A for the plastic frame. An X-ing error seems to be even more noticeable for metal frames when worn than for plastic frames.

With metal frames, X-ing may be corrected by grasping the lenses and eyewires between the thumbs and fingers as in changing the face form but applying the pressure in a rotary or twisting manner to align the lenses. As noted, care must be exerted to prevent stress at the lens/frame edge.

It may be possible to correct X-ing with two pairs of pliers. Using double-padded pliers, grasp the bridge in a manner similar to that shown in Figure 8.37. Move one pliers clockwise and the other counter clockwise to bring the two lenses back into the same plane. Although using the hands alone is easier and the preferable method for most, using pliers may reduce stress that might otherwise be placed on the eyewires.

Variant Planes

When the misalignment is that of the two lenses being in different lateral positions yet still parallel to each other (Figure 8.39), the frame can be corrected in one of two ways.

A metal frame with the problem of lenses out of coplanar alignment can often be handled in the same manner as was done for a plastic frame but without heating. The frame is bent with the hands by grasping the lenses and eyewires with the thumbs and fingers and forcing the frame into alignment as was seen in Figure 8.9. This is the most commonly used method.

If the first method will not work, the second method for variant plane correction uses two pairs of pliers and involves two procedures. First, grasp the bridge with two pairs of pliers, each a short distance from either eyewire. The pliers holding the bridge portion nearest the wearer's face (pliers A) are used to hold the frame, whereas the pliers gripping the bridge portion farthest from the face (pliers B) serve as the bending pliers (Figure 8.40). Bend the bridge as if increasing the face form until the nasal side of the bridge (which had been forward) is on

Figure 8.39 When lenses are out of coplanar alignment in a metal frame, the correct procedure for realignment is considerably harder to carry out than the procedure used for plastic frames.

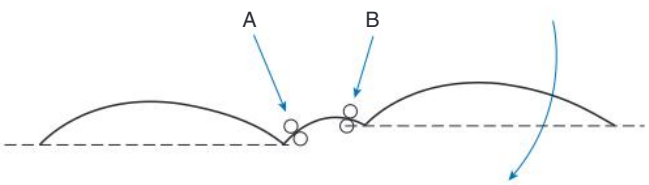


Figure 8.40 In beginning the correction of lenses out of coplanar alignment, the pliers holding the bridge portion nearest the wearer's face (*pliers A*) are used to hold the frame, while *pliers B* serve as the bending pliers.

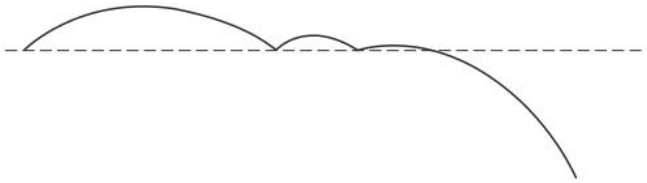


Figure 8.41 The bridge is bent as if the face form were to be increased until the nasal side of the bridge, which had been forward, is on the same plane as that of the other side of the bridge. The lenses now appear angled in relation to each other.

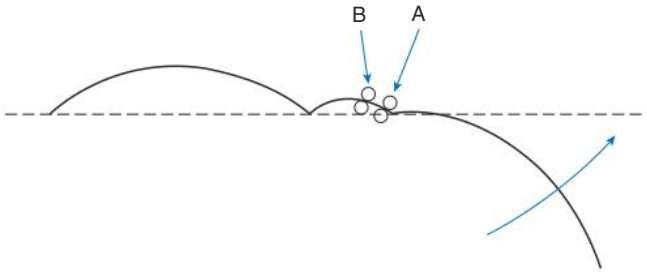


Figure 8.42 Now *pliers B* that previously did the bending is used as holding pliers. The other pliers (*pliers A*) are moved to that portion of the bridge between the eyewire and *pliers B*. The bridge is bent upward at this point by *pliers A* until the lenses are parallel.

Figure 8.43 The final stage in correcting for lenses out of coplanar alignment returns the metal frame to a four-point touch configuration.

the same plane as that of the other side of the bridge. The lenses will now appear to be angled in relation to each other (Figure 8.41).

Now using pliers B, which previously did the bending, as a holding pliers, move pliers A to that portion of the bridge between the eyewire and pliers B (Figure 8.42). Bend the bridge outward at this point with pliers A until the lenses are parallel (Figure 8.43).

THE TEMPLES

As with plastic frames, the temples are used to help gauge how the next frame area is to be adjusted, starting with the open temple spread.

Open Temple Spread

The temple should be at the same angle to the frame front as it was for a plastic frame, which customarily is a 94- to 95-degree angle. However, as in the case of plastic frames, if the frames come from the optical laboratory without enough temple spread, it is not usually desirable to spread the temples to more than 90 degrees before fitting them to the wearer. The reason is because, if the wearer's head is narrow, it then becomes necessary to reangle the temples inward again.

When Temples Are Spread Too Far (Decreasing the Temple Spread)

If the temples are spread too far apart, there are several ways to bring them back into alignment. Here are a few selected methods.

First method. Use a pair of half-padded pliers as bending pliers. Half-padded pliers have a small metal jaw on one side and a nylon-padded jaw on the other. Grip the outside of the endpiece (Figure 8.44). Hold the front firmly near the endpiece with the free hand. Rotate the bending pliers around until the temple has reached the desired temple-spread angle.

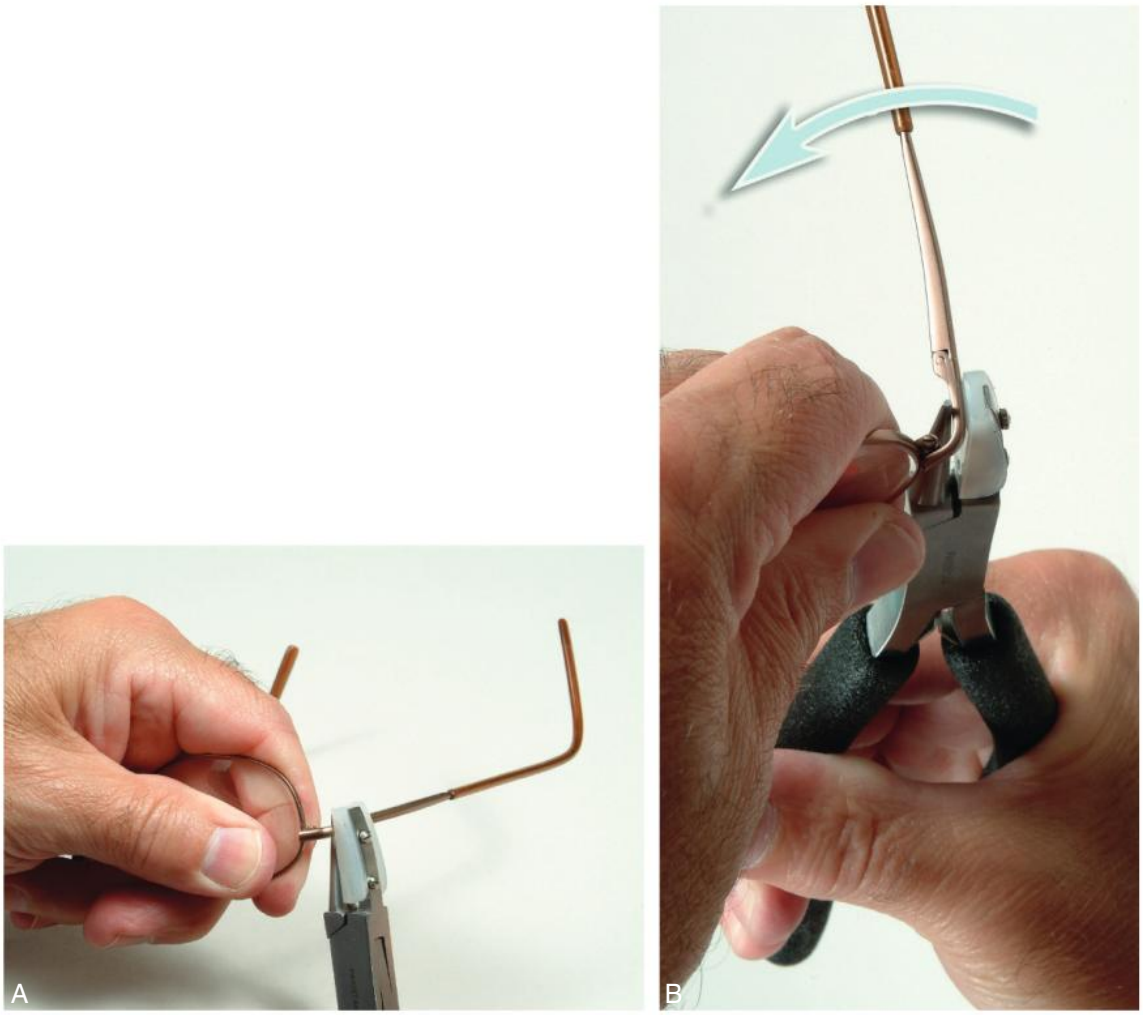


Figure 8.44 If the temples are spread too far apart, a pair of half-padded pliers may serve as bending pliers to grip the outside of the endpiece. **A,** Side view. **B**, Top view.

Second method. Close the temple, and grip the hinge from below with the thin pliers. (Since no visible external frame areas are being gripped, it is not essential that the pliers be padded.) Rotate the pliers, bending the endpiece area inward (Figure 8.45). Because of the risk of chipping the lens, whenever there is sufficient space available, use a second pair of pliers to grip the frame near the lens so that the eyewire area is not stressed (Figure 8.46).

Third method. The endpiece can be bent using another method that does not involve pliers but only a smooth flat surface. With both hands, hold the frame by the lens and eyewire just adjacent to the endpiece. (The closer to the endpiece the frame is held, the less danger there is of breaking a lens.) Hold the frame front perpendicular to the table surface, and push the endpiece against the surface until there is enough bend to hold the temple at its proper spread angle (Figure 8.47).

When Temples Are Not Spread Far Enough (Increasing the Temple Spread)

When the temple spread is too small, it can be increased by using the reverse of the first two methods described above for decreasing the temple spread.

First method. This is exactly the reverse of method one above. Grasp the outside section of the endpiece with padded pliers. (This is shown in Figure 8.44.) Bend the endpiece outward to the proper spread while supporting the front at its junction with the endpiece.

Second method. Use the reverse of the second method listed above. Close the temple, grasp the hinge, and bend the endpiece outward. As noted before, certain kinds of frames allow enough space at the endpiece to permit a second pair of pliers next to the eyewire as holding pliers. This takes any possible strain off the eyewire, reducing the possibility of chipping a lens.

For a summary of temple spread problem solutions, see Box 8.4.

Temple Parallelism (Changing the Pantoscopic Angle)

Temple parallelism refers to the relative pantoscopic angles as viewed from the side. Testing proper temple parallelism is done in exactly the same manner for metal frames as for plastic. (Alternately, the experienced dispenser can view the temples from the side and still be accurate.)

Place the glasses upside down on a flat surface, and note if one or both temples touch the surface (flat surface touch test). If the frame wobbles, the pantoscopic angle must be adjusted.

The normal pantoscopic angle varies anywhere from 4 to 18 degrees. By keeping this in mind, it is relatively easy to decide which temple to bend up or down. If the difference between the two angles is extreme, it

Figure 8.45 Use the hand to grasp the frame front firmly at the endpiece. Decrease temple spread with the pliers. If there is risk of chipping the lens, remove the lens first.

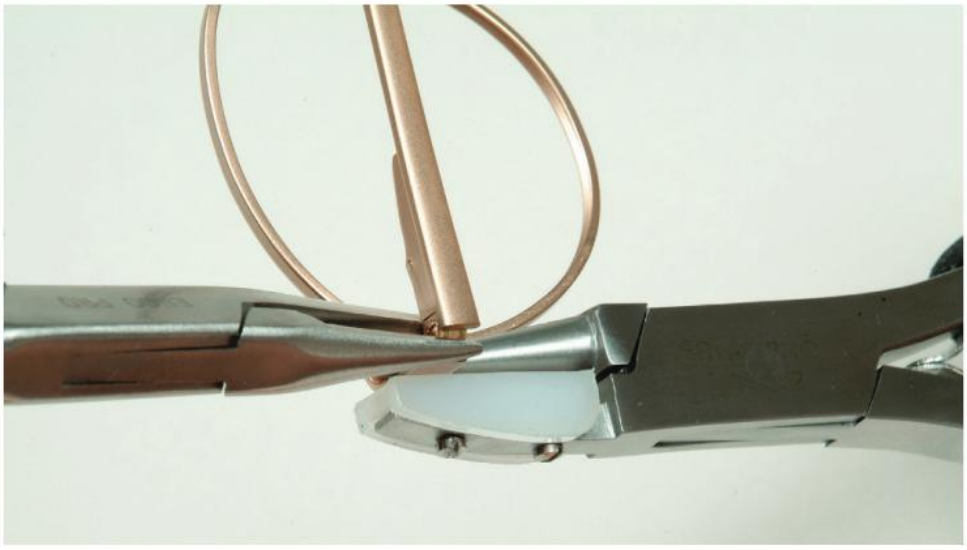


Figure 8.46 The risk of lens chipping can be reduced by using holding pliers while reducing temple spread.

may be necessary to bend one temple up and one down to make the angle equal on both sides. The classic beginner's mistake is to always bend the temple that is not touching the table top until it does. If this is done, and is left uncorrected, there will often be too little pantoscopic tilt on the frame when worn.

There are several ways to change the pantoscopic angle of a metal frame:

1. *Hands only*. The simplest way is to grasp the eyewire and lens close to the endpiece on the same side of the frame as the temple that needs to be angled and bend the temple up or down by hand. The frame will bend at the endpiece or at the hinge.

Though not desirable, it is sometimes necessary to close the temple a few degrees to allow the hinge to bend. One disadvantage to this method is that it may leave a V-shaped gap at the point where the temple butt and endpiece join. This should be avoided.

Changing the pantoscopic angle with the hands only is perhaps the most commonly used method because it is fast. However, it is not the best method.

Figure 8.47 To decrease temple spread, the frame front may be held perpendicular to a flat surface and the endpiece pushed against it.

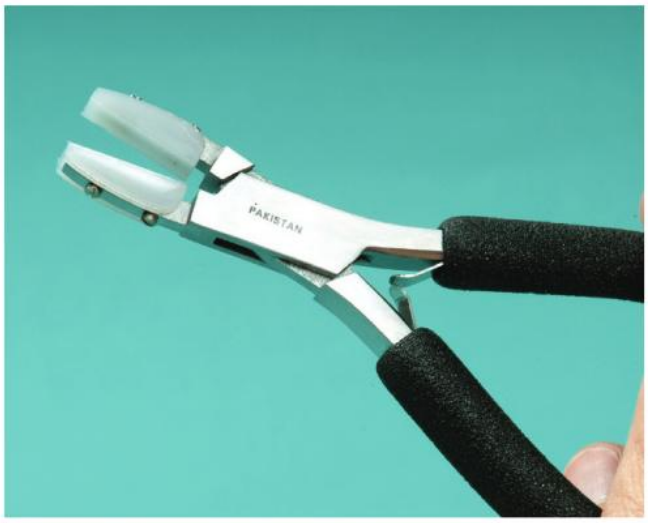


Figure 8.48 Double-padded pliers help to prevent marks on the frame during frame adjustment.

BOX 8.4 Alternative Methods of Increasing or Decreasing the Temple Spread on Metal Frames

1a. Grasp the endpiece with the hand (or when possible, use thin half-padded pliers as holding pliers).
1b. Use thin-padded or half-padded pliers as bending pliers and grasp the endpiece near the hinge. Bend the endpiece in or out.
2. Close the temple, grip the hinge barrels, and bend the endpiece either inward or outward.
3. Push the outside of the endpiece against a flat surface to bend the endpiece inward.

2. *Two padded pliers.* Using a pair of bracing pliers with one metal and one nylon jaw (half-padded pliers), hold the endpiece on the front of the frame if there is room or just anterior to the hinge if there is not. The second pliers, used for bending, should be double-padded pliers (Figure 8.48) to grasp the temple close to or directly on the hinge. It may be prudent to remove the lens if the frame is stiff or there appears to be a possibility of chipping the lens. Grasp the frame as shown in Figure 8.49, and reangle it up or down.
3. *One hand and one double-padded pliers.* It may be possible to do the bend as described in the previous method without a pair of bracing pliers. This may be done by grasping the endpiece and temple from the front with the double-padded pliers parallel to the temple as shown in Figure 8.50.
4. *One hand on frame front and angling pliers.* Another method of changing the temple angle is to bend the endpiece with angling pliers. (This method is usually the most successful.) Grip the hinge by the screw head and tip of the screw with the angling pliers (Figure 8.51, *A* and *B*). Holding the frame front firmly, rotate the angling pliers until the desired angle is reached. The front may be held by the hand near the endpiece, or the endpiece may be secured with pliers to better ensure against chipping the lens. (*Do not* grasp the top and bottom of the temple with the angling pliers. Grip only the screw and hinge. Otherwise the temple will be visibly damaged.)

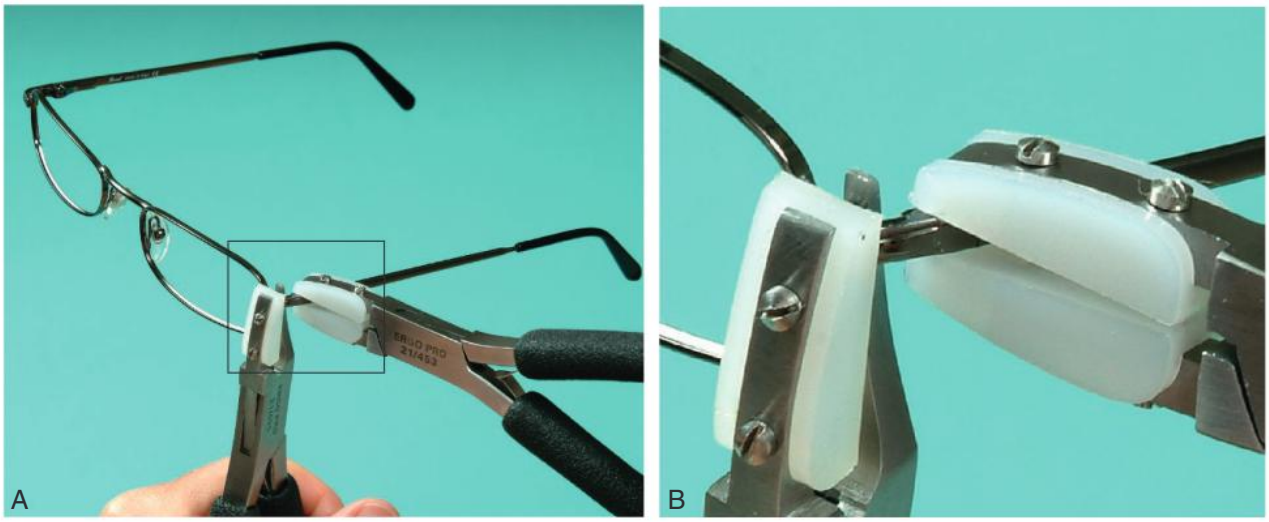


Figure 8.49 **A,** To change the pantoscopic angle, hold the endpiece, grasp the top and bottom of the hinge area, and reangle the temple. **B,** Close-up view.

Figure 8.50 When the endpiece is too small, the pantoscopic angle can be changed without holding pliers. If the frame does not have enough flexibility, the lens may be removed first.

5. *Gripping the eyewire screw.* When one method does not seem to work or helps but does not fully accomplish the task, there must be other ways to do the same thing. With some frames it is possible to change the pantoscopic angle by grasping the eyewire screw and angling the temple as shown in Figure 8.52. Only frames constructed in certain ways will allow for this, and this should not be used as the first attempt to change the pantoscopic angle. It torques the eyewire and could chip the lens.
6. *Angling pliers and one hand on temple.* Angling pliers may be used to change the pantoscopic angle without affecting the endpieces. This may be useful if the endpieces appear to be even. Grip the hinge with angling pliers in the customary manner. This time, however, do not rotate the pliers; instead, use them as holding pliers. With the other hand, bend the temple shaft down (Figure 8.53). The pantoscopic angle correction is produced by a change in the hinge angle instead of by a change in the endpiece angle. The cosmetic result of this method may be less than desirable as it may produce a visible angle between a wraparound endpiece and the temple.

For a summary on changing the pantoscopic angle with metal frames, see Box 8.5.

Aligning the Temple Ends

The earpieces (bent-down portions) of metal frame temples are aligned in the same manner as that used for plastic frames. Several precautions must be taken, however, to keep from damaging the frame during the adjustment process.

The conventional skull temple on a metal frame usually has a plastic covering over the end of the temple. This affords a more comfortable fit. Because of the plastic, it is usually necessary to apply some degree of heat to this part of the frame before it can be manipulated. Different types of temples require varying amounts of heat.

Temples with a clear plastic covering heat very quickly and should be heated only slightly (just slightly warmer than body temperature). The plastic can easily be bubbled by overheating or distorted by being

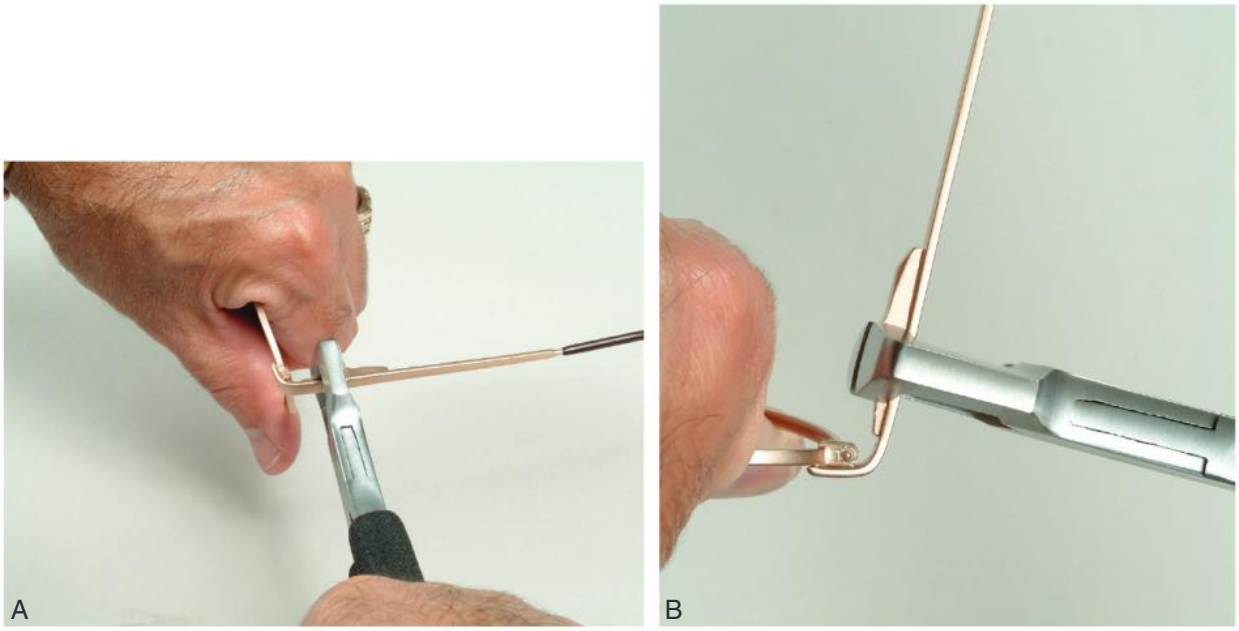


Figure 8.51 The pantoscopic angle of the temple may be changed by gripping the top and bottom of the temple screw with angling pliers and bending the temple upward or downward. This is shown from a side view in **A** and from a top view in **B.**

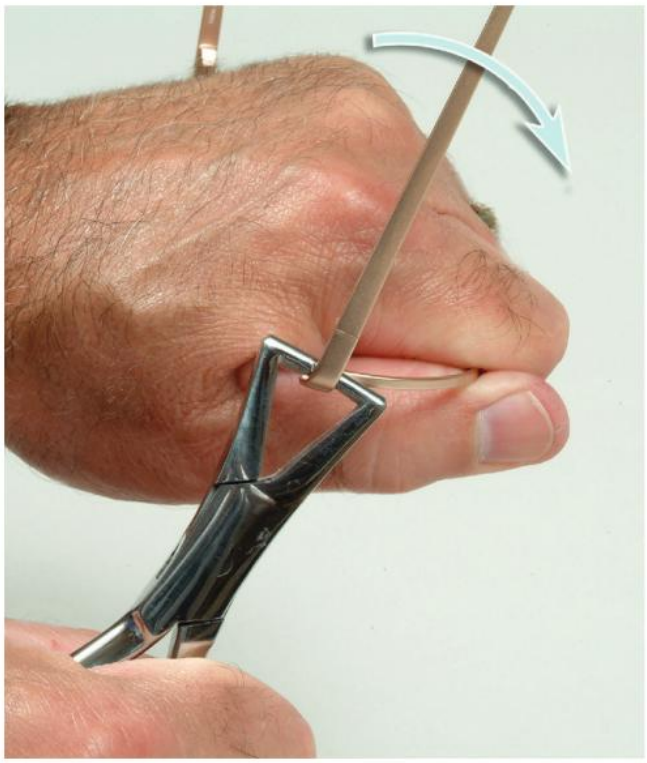


Figure 8.52 Here, the pantoscopic angle is changed by grasping the eyewire screw instead of the hinge. Notice that thin angling pliers are used because the standard angling pliers may be too bulky to get into this small area. This method presents a risk of chipping the lens because of the torque it applies to the eyewire and thus to the lens as well.

bent while too pliable. New frames bend quite satisfactorily at low or sometimes even room temperature depending upon design and material. The plastic in old frames, however, is usually too brittle to bend without more extensive heating.

Other frames have a fairly heavy piece of metal running through the temple ends. These frames exhibit more resistance to bending because of the thickness of the metal. A common error is to assume that this resistance is due to insufficient heating. The result is overheating and distortion of the plastic when bent. To prevent this error, heat the entire plastic portion slightly, but concentrate the heat on the portion that must absorb the bend. Intermittently heating the area and removing it from the heat will allow the heat to penetrate to the core and will even out the heat. Otherwise, the exterior may be too hot and the interior not hot enough. Quite a bit of force may be necessary even when the heating is done correctly.

BOX 8.5 Alternative Methods of Changing the Pantoscopic Tilt on Metal Frames

1. a. Grasp frame front close to hinge.
   b. Bend temple up or down by hand.
2. a. Hold the endpiece with half-padded pliers (see Figure 8.48).
   b. Grasp temple on top and bottom of hinge with double-padded pliers.
   c. Bend up or down.
3. a. Hold frame front with hand (see Figure 8.50).
   b. Grasp temple on top and bottom of hinge with double-padded pliers.
   c. Bend up or down.
4. (Recommended)
   a. Hold front near endpiece with hand (see Figure 8.51).
   b. Grip hinge with angling pliers.
   c. Bend with pliers.
5. a. Hold front near endpiece with hand.
   b. Grasp eyewire screw with angling pliers (see Figure 8.52).
   c. Bend with pliers.
6. a. Hold hinge steady with angling pliers (see Figure 8.53).
   b. Grasp temple with hand and bend down.

Temple-Fold Angle

The procedure for changing the temple-fold angle in a metal frame varies according to the type of endpiece being used. Three methods are presented here. One uses double-padded pliers, the second half-padded pliers, and the third endpiece angling pliers.

In the first method, hold the frame front firmly in one hand, and grip the top and bottom of the hinge area with double-padded pliers similar to the manner pictured in Figure 8.54, *A*. Rotate the pliers in

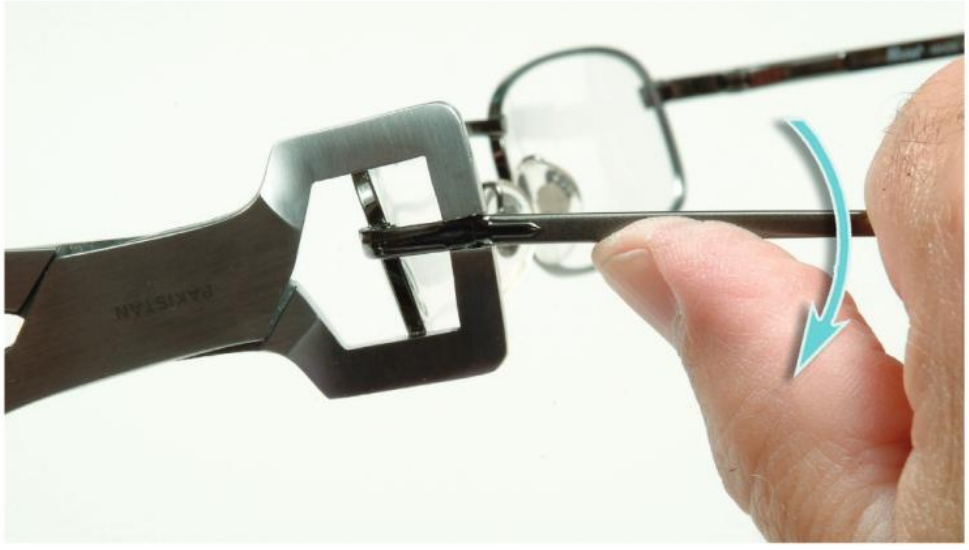


Figure 8.53 The temple angle may be changed by bending the hinge instead of the endpiece itself. This can be done using angling pliers to hold the hinge with one hand while the temple shaft is bent down with the other hand.

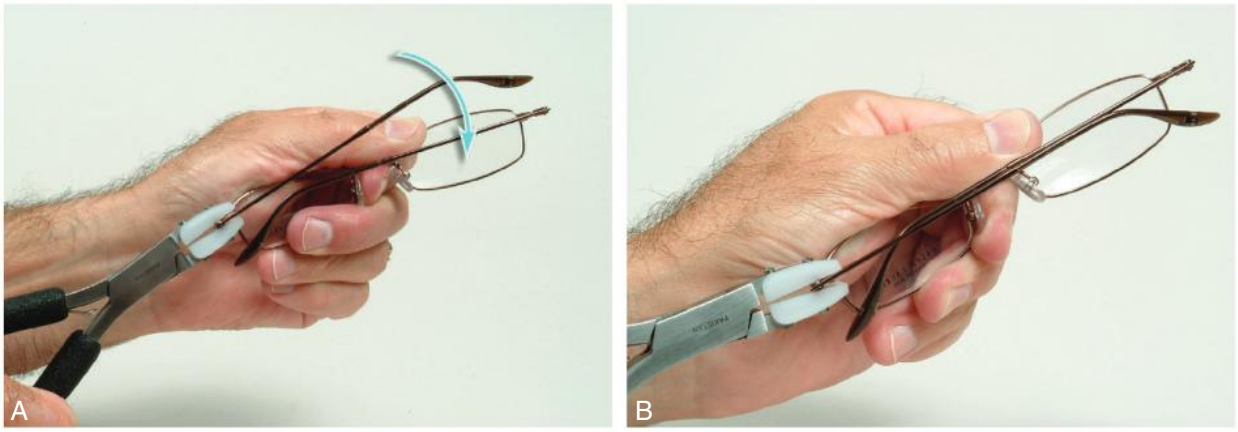


Figure 8.54 To change the temple-fold angle on commonly used types of metal frames, hold the frame front in the hand firmly, temples closed. Grip the top and bottom of the hinge area with double-padded pliers as shown in **A,** and bend the temple so that it returns to and maintains its correct parallel alignment as seen in **B.**

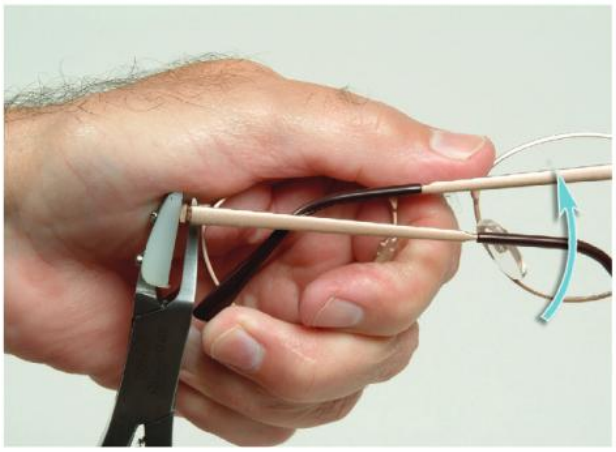


Figure 8.55 The temple-fold angle may be changed using half-padded pliers on the endpiece and bending the folded temple to parallel. It is also possible, and usually preferable, to make this adjustment using endpiece angling pliers in the manner previously shown in Figure 8.33 for plastic frames.

the direction necessary to line up the temples in their correct parallel alignment (see Figure 8.54, *B*).

In the second method, the frame front is held by hand in the same manner as method one. With temples closed, the endpiece is gripped with the half-padded pliers as shown in Figure 8.55. The temple is turned until parallel.

The third method uses endpiece angling pliers. This was shown previously with plastic frames in Figure 8.33. The pliers are held at right angles to the frame front, gripping the screw and hinge only—not the top and bottom of the temple! If there is sufficient room for the pliers, this is the safest and most successful method.

SECTION C: STANDARD ALIGNMENT OF NOSE PADS

As with the frame front and the temples, there is a specific standard alignment for nose pads that should be used during the preliminary adjustment of the frame. Obviously, final adjustment of the pads will vary extensively with the individual shape, width, and flare of the nose of the intended wearer. However, pads adjusted to a proper standard initially facilitate individual adjustment later.

There are three basic angles that are used for reference when aligning nose pads. These are the frontal, splay, and vertical angles. To be in standard alignment, these angles must fall within certain limits and be the same for both right and left nose pads.

FRONTAL ANGLE (VIEWED FROM THE FRONT)

The *frontal angle* of the nose pads refers to the vertical position of the pads in relation to each other when viewed from the front. The tops of the pads should be closer together than the bottoms. Pads angle toward each other at approximately 20 degrees from a true vertical for each pad (Figure 8.56).

Most pads can be "rocked" about a swivel joint. The pads should be slanted for the frontal angle by the same amount. This is most easily done using pad-adjusting pliers to grip the pad as a whole. Pad-adjusting pliers are made in a variety of ways depending upon the construction of the nose pads for which they are intended (Figure 8.57). The frame front is held securely in one hand and the pad angled by turning the pliers to the angle desired (Figure 8.58).

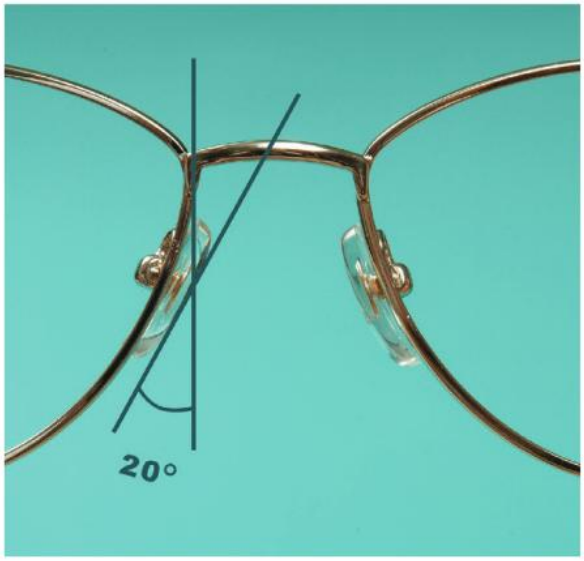


Figure 8.56 In standard alignment of nose pads, the angle most clearly seen when viewing from the front is termed the *frontal angle.*

Figure 8.57 The type of pad-adjusting pliers used will depend on the type of pad on the frame.

When evaluating one of the pads, the play exhibited by that pad should be equal on each side of the desired position for the correct frontal angle. In other words, a pad should not have to be rocked to one extreme in order to match the frontal angle of the other pad.

If one pad has a lot more play in the *amount* of rock it shows, the amount of play may be reduced on some pad types by tightening the looser pad with pliers. The way this might be done depends upon how the pad is made. For example, it may be done on some pads by pressing on the attachment point with one jaw while the other rests on the face of the pad. For pads that slip into a small box on the pad arm, tighten the amount of rock by crimping the box into which the back of the pad snaps.

Pad Spacing

While viewing the frontal angle, observe the amount of space between the eyewires and pads. Both pads should be equidistant from their respective eyewires. An estimated ideal position is for the face of the pads to appear approximately 1 mm closer to the nose than the eyewire itself (Figure 8.59). If the pads are spread too far apart, the rim of the frame could possibly rest directly on the nose. Both pads should also be of equal distances from their respective eyewires; otherwise, the frame will not center properly on the face. Proper correction procedures for these errors are described in detail in Chapter 9 when discussing changing the distance between pads.

Pad Height

A third point of observation is whether or not both pads occupy the same horizontal plane (see Figure 8.59). If one pad appears higher than the other, the pad arm may be bent upward. It is essential that both pads be in identical rocking positions because if one is erect and one is slanted, their heights may appear dissimilar. Again, specifics of adjustment technique are described fully in Chapter 9 in the sections that review changing the height of pads.

SPLAY ANGLE (VIEWED FROM THE BOTTOM OR TOP)

Remembering that the nose is wider at the base than at the bridge and that the face of the pads should rest fully on the nose, it is apparent that the back edges of the pads should be farther apart than the front edges.

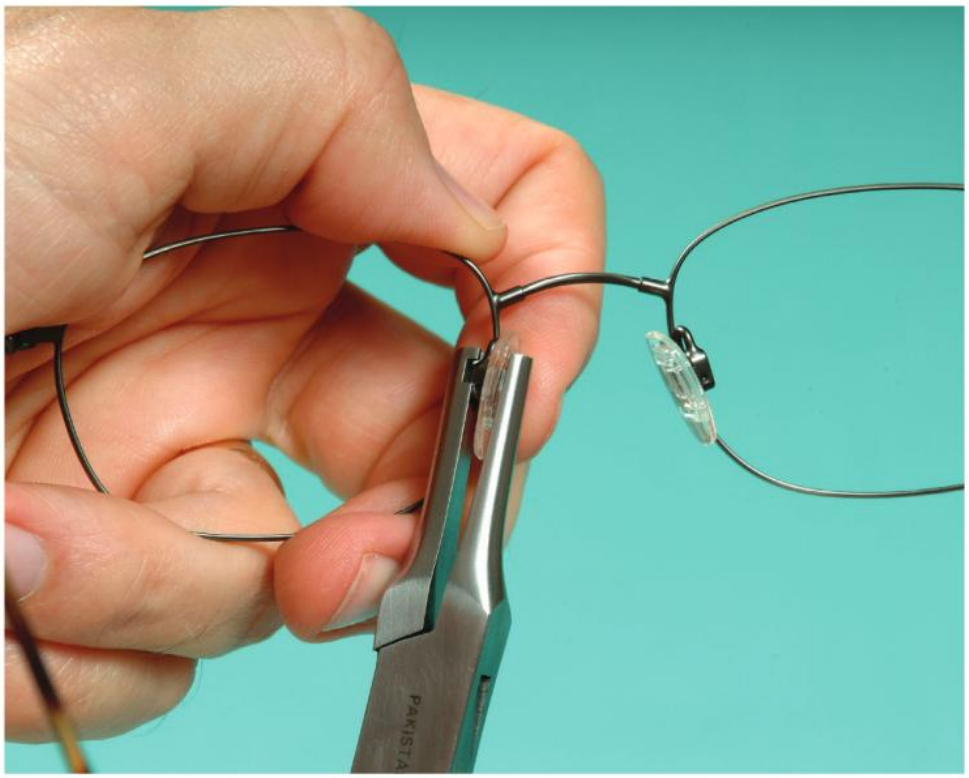


Figure 8.58 The correct method for using pad-adjusting pliers.

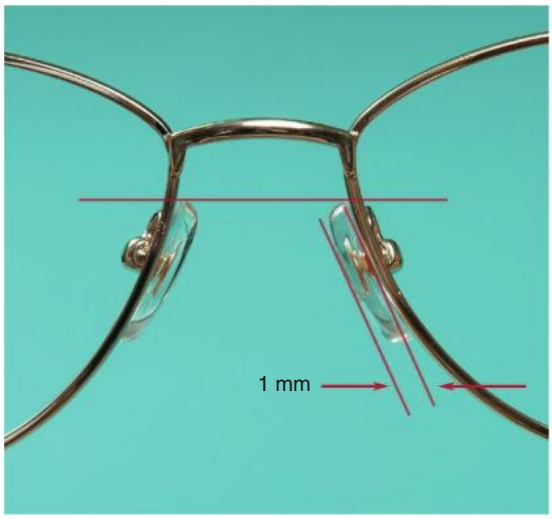


Figure 8.59 An estimated ideal position is that in which the faces of the pads appear approximately 1 mm closer to the nose than the eyewire itself. (Note: This is not 1 mm between the frame eyewire and the back of the pad.) Also, both pads should be at the same height as shown by the horizontal red line.

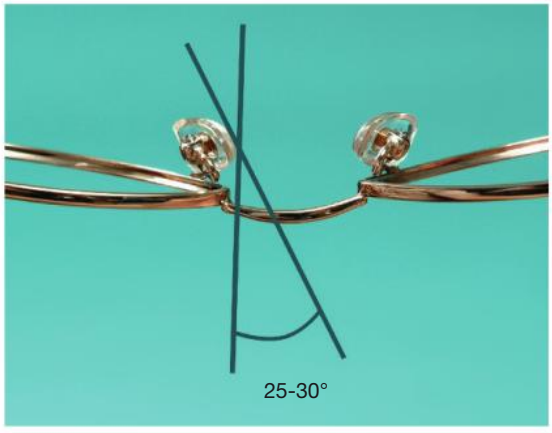


Figure 8.60 The second angle of concern in the proper alignment of nose pads may be seen by viewing the frame either from above as shown here or from below. This angle is referred to as the *splay angle*.

This difference between the back and front edges of each pad, viewed from the top or the bottom, is the *splay angle*. Viewing from the bottom affords the best perspective. For initial alignment, a splay angle of 25 to 30 degrees is satisfactory (Figure 8.60) and may be achieved through the use of the pad-adjusting pliers.

VERTICAL ANGLE (VIEWED FROM THE SIDE)

The angle most often neglected in the standard alignment of nose pads is the *vertical angle*. This angle is especially important in ensuring proper weight distribution under the pad. Ideally, the longitudinal (top-to-bottom) axis of the pad face is in contact with the nose surface in the direction of gravity. In other words, the longitudinal axes of the pads should be vertical on the face. (If the nose pads are round instead of elongated, there is no vertical angle.)

Since most spectacles are worn with a certain amount of pantoscopic tilt, the pads must be inclined so that the bottoms are closer to the frame front than the tops. Then, when the glasses are positioned

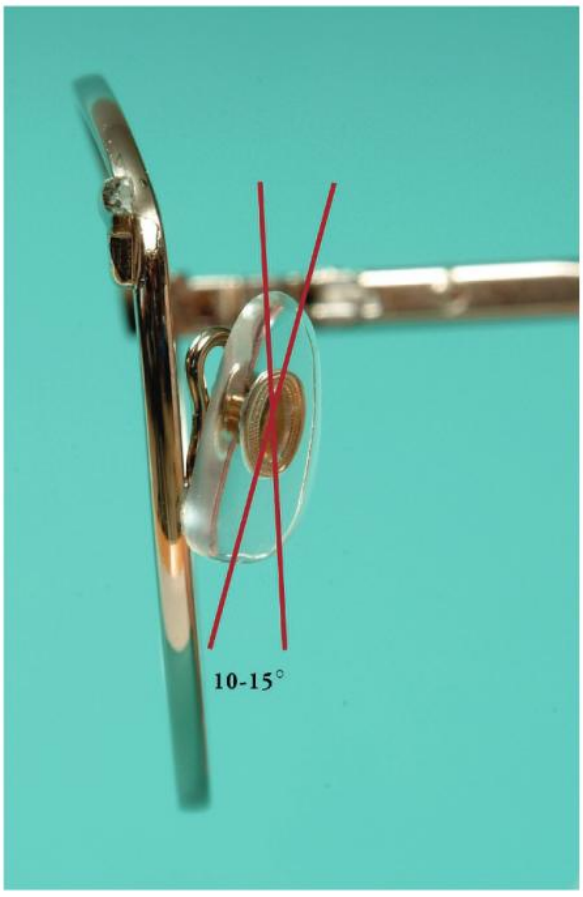


Figure 8.61 The angle often neglected in the standard alignment of nose pads is the *vertical angle*. This angle is especially important in ensuring proper weight distribution under the pad. When the glasses are worn, the frame front will not be straight up and down, but it will be angled. The long axis of the pad will be straight up and down.

on the nose with their proper pantoscopic angle, the pads will be approximately vertical (Figure 8.61). This means that the vertical angle of the pad should approximate the pantoscopic angle. For initial standard alignment, a vertical angle of approximately 15 degrees is acceptable. This may be achieved in one of three ways:

1. *Using pad-adjusting pliers.* Grasp the pad on its surface with the pliers as shown in Figure 8.58 and rotate. (It may be necessary to grip the pad from the top instead of the bottom to adjust the vertical angle.)
2. *Thin-nosed pliers on the pad arm.* For adjusting the vertical angle, because there may not be room to do this adjustment with pad-adjusting pliers, thin-nosed pliers are used. The pad arm is grasped directly behind the pad from above or below.
3. *Grasping the box behind the pad arm.* Some nose pads are attached to the pad arms with a small box. It is possible to reangle some pads by grasping the box behind the pad. This is shown in Figure 8.62.

Pads Must Have Equal Distances From the Frame Front

While viewing from the side to check for the proper vertical angle, also note the distance of each pad from the front of the frame. Both pads should extend back an equal distance. The pads should be equal not only in height and inclination but also regarding this distance. If these three details are precise, one pad will practically hide the other when the pair is observed directly from the side. To correct for an error of this nature, use the techniques described in Chapter 9 in the sections on changing the height and vertex distance of pads.

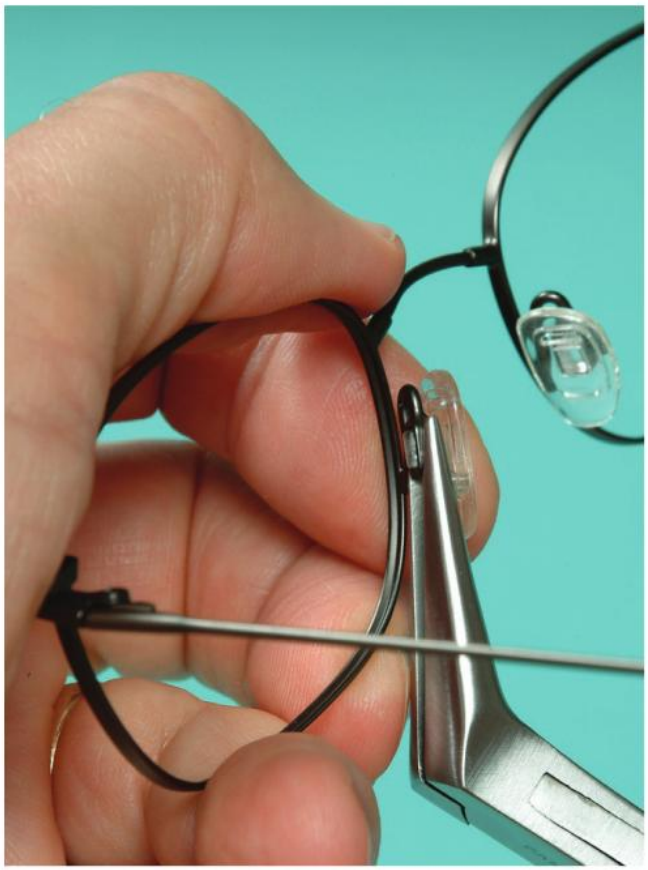


Figure 8.62 If one of the pad angles is out of adjustment, it is possible to correct the angle by grasping the box behind the pad with snipe-nose pliers from above or below.

A Humorous Way to Remember the Three Pad Angles

Here is a clever way to remember which pad angle is which and how they move[1]:

1. Put your thumbs under your arms and flap your arms like a chicken. This movement corresponds to the frontal angle.
2. Hold your hand straight up in front of you and rotate your wrist in the typical "Miss America" wave. This mimics the splay angle.
3. Imagine being the person on the tarmac at the airport using two orange flashlights to direct an airplane taxiing toward you. To get the plane to move directly toward you, you hold the flashlights straight up and down. Now, bending your elbows, move both flashlights forward and backward. This corresponds to the vertical angle.

SECTION D: STANDARD ALIGNMENT OF RIMLESS EYEWEAR

RIMLESS CONSTRUCTION AND LENS MATERIALS

In the past, rimless eyewear was the most fragile of eyewear. This made the alignment and adjusting of rimless glasses tedious and risky. It was easy for the glasses to lose their alignment with active wear and not uncommon to crack a lens. Now, when proper lens materials are chosen and the appropriate tools are used in the adjustment process, results and safety are excellent.

Newer rimless designs use a variety of methods to give extra stability to the mounting. In the past, the lens was held in place with one hole nasally and one hole temporally. Now there may be more than one hole, or a slot, or holes and edge notches used in combination. As a result, these constructions hold their adjustment.

Appropriate Lens Materials

If appropriate lens materials are used for rimless mountings, lens chipping is vastly reduced. At the time of this writing, the best lens material for rimless mountings is Trivex. Polycarbonate is also safe but may develop small stress fractures next to the drilled hole. Many labs will only warranty Trivex.

Many high-index plastic materials are suitable for rimless lenses but may not perform as well as either Trivex or polycarbonate. Conventional CR-39 plastic is not a good choice.

Glass lenses were used in rimless mountings years ago; they should not be used now. Chemically tempered glass is physically possible to use with rimless lenses but inappropriate. Heat-treated glass lenses are impossible. The combination of strain patterns produced by the heat treatment and the induced strain at the mounting points will result in a broken lens in short order.

ALIGNING THE BRIDGE

An alignment reference for rimless mountings is the *mounting line*. The mounting line passes through the nasal lens mounting points. The temporal lens mounting points may be on the same horizontal line as the nasal mounting points or may be equidistant above or below this mounting line. The important aspect here is not how far up or down on the glasses this line may fall. Rather, it serves as a horizontal reference in the alignment process.

Horizontal Alignment

Horizontal skew can be noted by placing a straight edge at the mounting line or parallel to it. If the temples are attached to the lenses on the mounting line, all four points should line up on the straight edge of a ruler. If the temples are not attached on the mounting line, the ruler is placed on either the two nasal or the two temporal points. The points of attachment of the remaining reference points should then be equidistant from the straight edge (Figure 8.63).

If the lens is out of horizontal alignment and the frame is new, there is a chance that one lens has been improperly drilled. It is also possible that the bridge is bent. Figure 8.64 shows a mounting that is out of horizontal alignment. The problem may be corrected as follows:

1. *Using rimless bracing pliers and double-padded pliers.* One of the issues with rimless mountings is protecting the lens mounting points from stress during the adjustment process. Too much stress on the lens at the mounting point can cause the lens to loosen or fracture. The type of pliers designed for reducing mounting point stress are referred to as rimless bracing pliers. One example of such pliers is shown in Figure 8.65. The bridge may be realigned by holding a nasal mounting point with bracing pliers, grasping the bridge with double-padded pliers, and bending the bridge as shown in Figure 8.66.
2. *Using two pair of double-padded pliers.* A rimless bridge can also be corrected for horizontal misalignment using two pair of double padded pliers as shown in Figure 8.67.

Vertical Alignment (Four-Point Touch)

After horizontal alignment has been corrected, the next step is checking for a four-point touch. This is done in approximately the same manner as for plastic or metal frames. Place a straight edge on the inner sides of the lenses somewhat below the pads (Figure 8.68, *A*). In theory, the

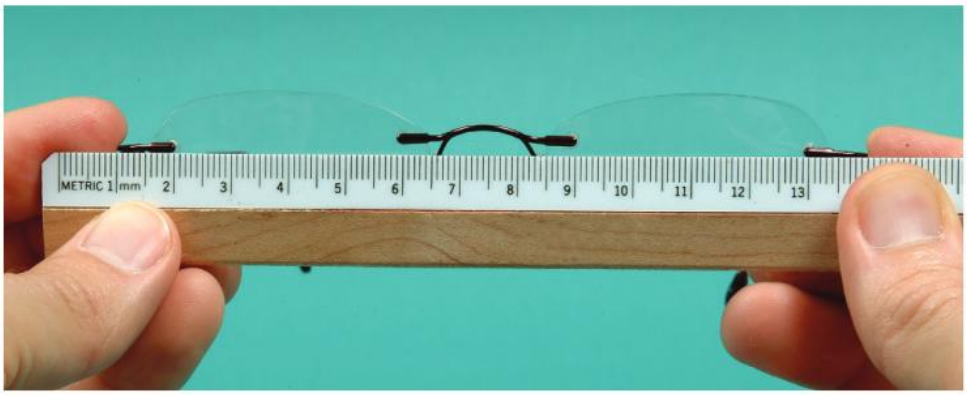


Figure 8.63 Checking the horizontal alignment of a rimless pair of glasses. Here, the ruler is placed on the temporal mouting points. The nasal mounting points should be equidistant from the ruler.

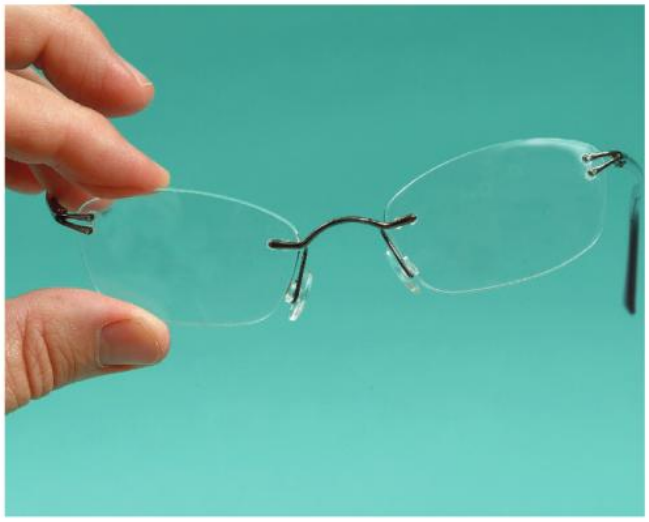


Figure 8.64 This rimless mounting is out of horizontal alignment.

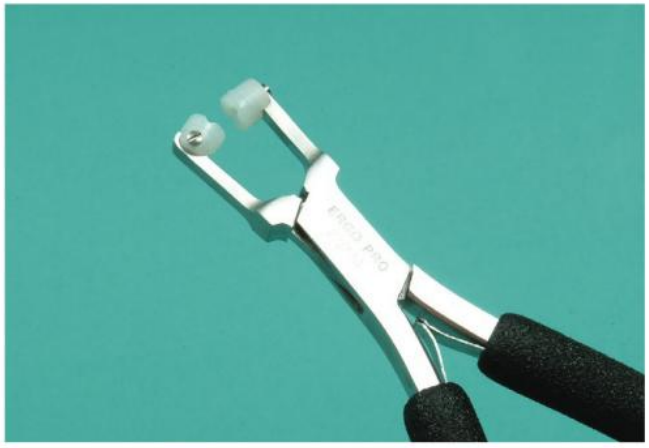


Figure 8.65 Rimless bracing pliers are used to hold rimless eyewear at the point of attachment to the lens. With this particular type of pliers, one jaw is fixed, and one jaw pivots. The jaw that pivots (in this figure, the jaw on the left) is to be placed on the front surface to compensate for the lens base curve.

nasal and temporal sides of both lenses should touch the straight edge. Then, repeat the test by placing the straight edge somewhat above the pads (see Figure 8.68, *B*). The nasal and temporal sides of both lenses should again touch the straight edge. (In practice, because the wearer's PD is usually smaller than the frame PD, face form is required, and the nasal lens edges may not necessarily touch the straight edge, but they must be equidistant from it.)

X-ing

If the nasal and temporal sides of both lenses in *both* upper and lower positions do not touch the straight edge, X-ing of the lenses has occurred. Because of the way rimless lenses are mounted, it would be possible to have a four-point touch exactly in the center of the lenses but still have X-ing. For that reason, the four-point touch test is done at both the top and the bottom of the lenses.

Face Form

While testing for a four-point touch, it may be found that too little or too much face form exists. To increase or decrease face form, grasp the mounting at a nasal point of attachment with rimless bracing pliers, and bend the bridge backward or forward using double-padded pliers (Figure 8.69). The bend in the bridge will take place between the two pliers. For maintaining symmetry, it may be helpful to partially bend the bridge, switch the rimless bracing pliers to the nasal point of attachment of the other lens, and complete the bend.

THE TEMPLES

In the sequence of standard aligning rimless mountings, the temple area is considered next, just as it is with plastic and metal frames.

Open Temple Spread

If the spread of one or both temples is at too great (Figure 8.70) or too small an angle, the error may be corrected by *bending the endpiece.* To do this, grasp the temporal point of attachment of the lens with rimless bracing pliers. Then, grip the endpiece with half-padded pliers from either above (Figure 8.71, *A*) or below (see Figure 8.71, *B*). The unpadded jaw of the pliers must be on the inside of the endpiece. If the temple is spread too far, the endpiece is bent inward as is shown in Figure 8.71, *C*.

It is also possible to increase or decrease the temple spread by using a *tri-angling plier.*[2] Tri-angling pliers have two round parts to one side of the pliers and a single, rounded section on the other jaw. By

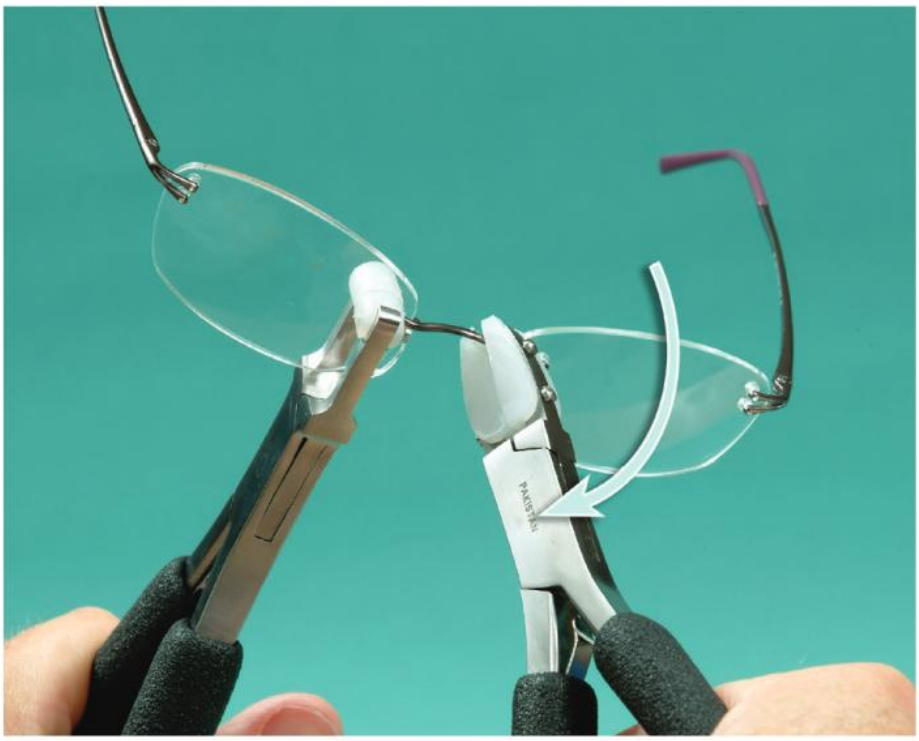


Figure 8.66 Here is one method for adjusting horizontal alignment using a combination of rimless bracing and double-padded pliers. To correct the horizontal misalignment shown in Figure 8.64, hold the nasal point of attachment with the rimless bracing pliers and bend the bridge downward with the double padded pliers.

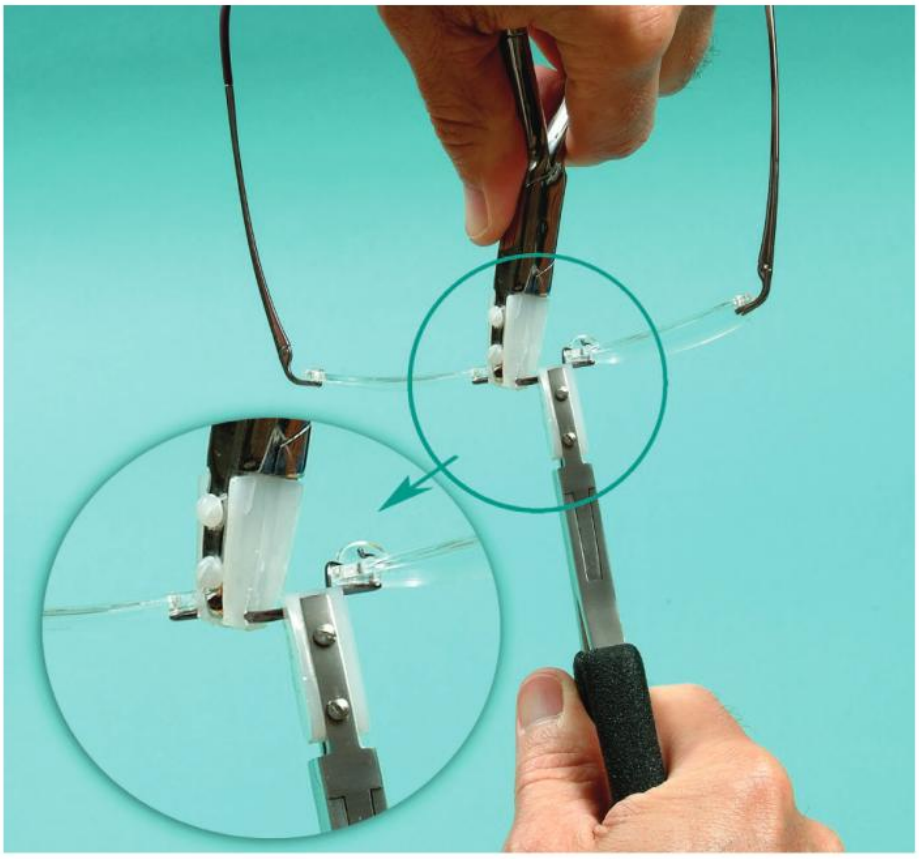


Figure 8.67 Horizontal misalignment may also be corrected by grasping the bridge with two pairs of double-padded pliers. This is still the same frame with the same misalignment as shown in Figure 8.64. Here, the frame is viewed from the top. The left pliers hold the bridge, replacing the rimless bracing pliers. The right pliers bend the bridge downward to realign it.

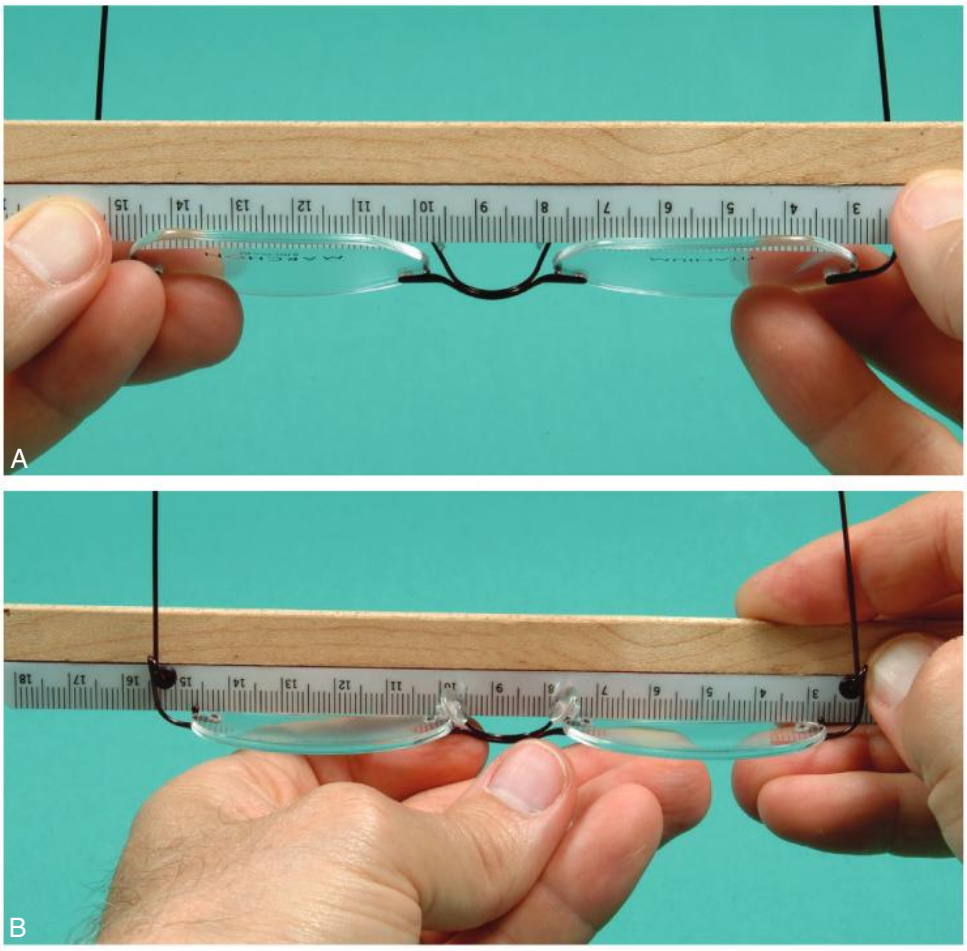


Figure 8.68 **A,** The check for four-point touch on a rimless mounting begins by placing the straight edge on the inner side of the lenses *below* the pads. **B,** The check for four-point touch on a rimless mounting is completed by placing the straight edge on the inner side of the lenses *above* the pads. By checking both above and below the nose pads, it is easier to tell if the bridge has any propeller-like X-ing effect.

Figure 8.69 To increase or decrease face form, grasp the mounting at a nasal point of attachment with rimless bracing pliers, and bend the bridge backward or forward using double-padded pliers.

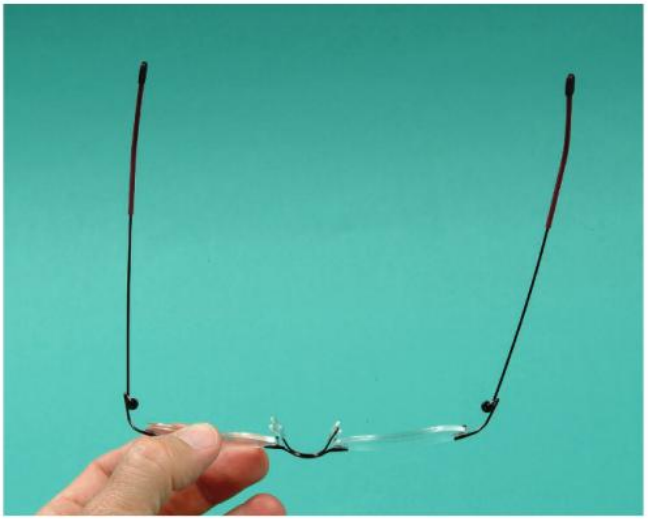


Figure 8.70 The right temple of this rimless mounting is spread too far and must be realigned.

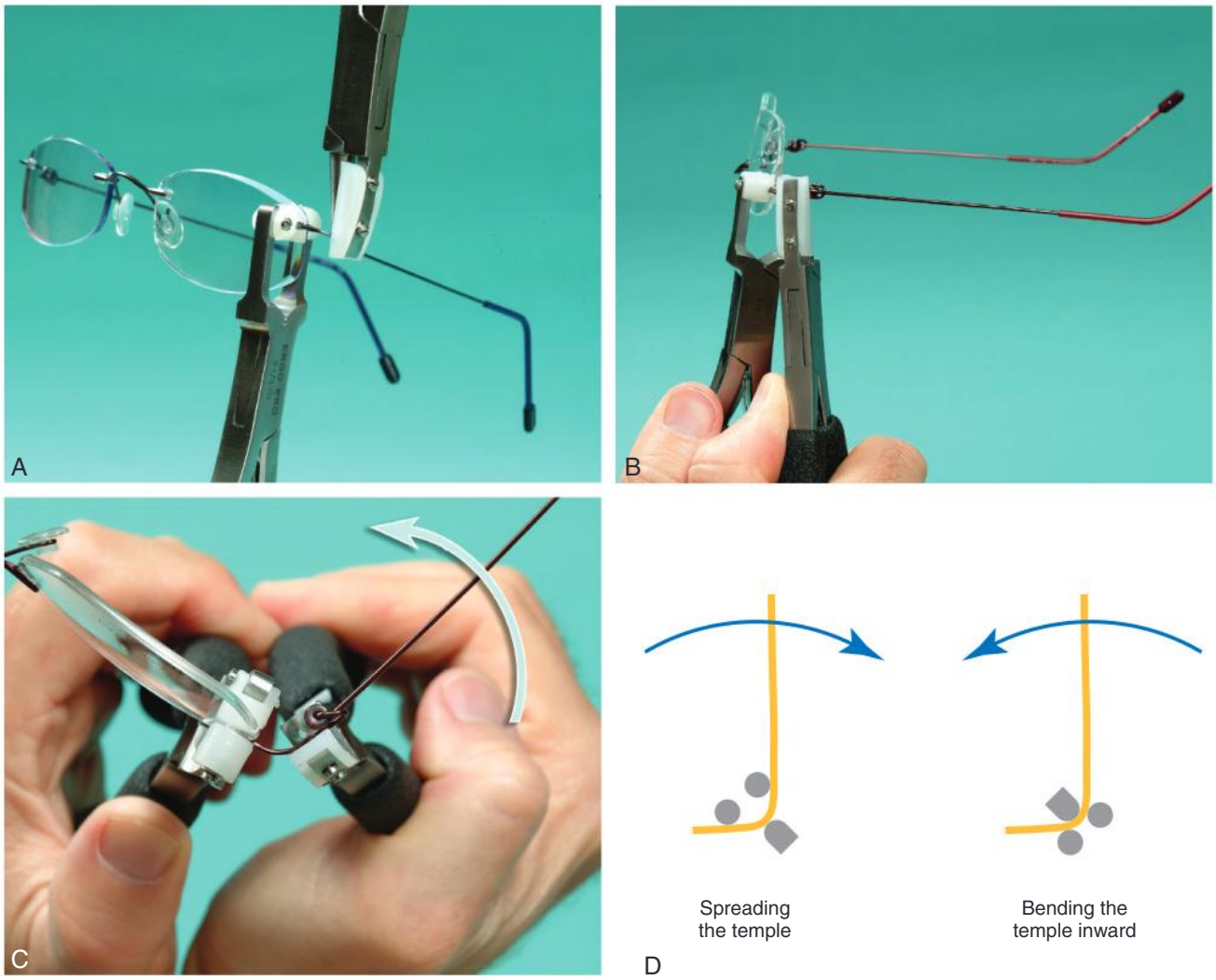


Figure 8.71 **A,** To increase or decrease the temple spread for a rimless mounting, grasp the temporal point of attachment of the lens with rimless bracing pliers. Then, grip the endpiece with half-padded pliers from above, and bend the endpiece either outward or inward. **B,** Some may prefer to grip the endpiece area from below with both pliers to bend the endpiece in or out. **C,** Hold the frame front steady with rimless bracing pliers (*left*), and rotate the half-padded pliers to bend the endpiece, bringing the temple inward or outward. **D,** Tri-angling pliers may be used to increase or decrease temple spread on certain rimless frames without putting stress on the lenses.

positioning and squeezing the pliers as shown in Figure 8.71, *D*, the temple spread may be increased or decreased. This type of plier may also be used to adjust other types of frame corners such as nylon cord frames or to reshape a clip-on to match the shape of the frame. Care must be taken not to mar the frame. This is done by putting cloth or tape in between the pliers and the frame.

If it is not possible to bend the endpiece, then *bend the temple*. Do this by gripping the butt end of the temple with pliers as close to the hinge as feasible. Then, grasping the temple as close to the pliers as possible with the thumb and forefinger of the free hand, bend the temple itself.

Temple Parallelism

Using the flat surface touch test previously described for plastic and metal frames or by viewing the temples from the side, check the parallelism (relative pantoscopic angles) of the temples. If one temple does not touch the flat surface table top, the cause may be a bend in the temple itself either at the attachment to the frame or just before the curl of the endpiece. This can easily occur with comfort cable temples as seen in Figure 8.72. A bend may be easily overlooked if it is gradual, extending the length of the shaft. Whatever type of unwanted temple shaft bend, the solution is simply to remove the unwanted bend. This is usually done by using the hands alone.

If the temple itself is not bent and there is no X-ing in the bridge, the fault lies in the angle of the endpiece. Figure 8.73 shows what this error looks like. Here are some commonly used methods for correcting what is basically a difference in right and left pantoscopic angles.

Using rimless bracing and double-padded pliers. Open the temple, and grasp the lens at the temporal mounting point with the rimless bracing pliers. Using double-padded pliers, grasp the endpiece as shown in Figure 8.74, *A* and *B*. Then, rotate the double-padded pliers so

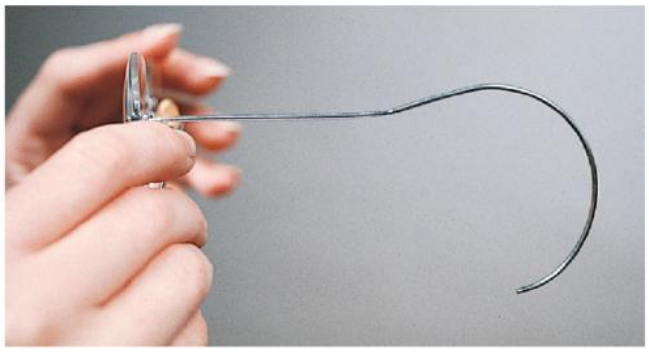


Figure 8.72 An unwanted bend may occur at the position on a cable temple where metal coiling begins.

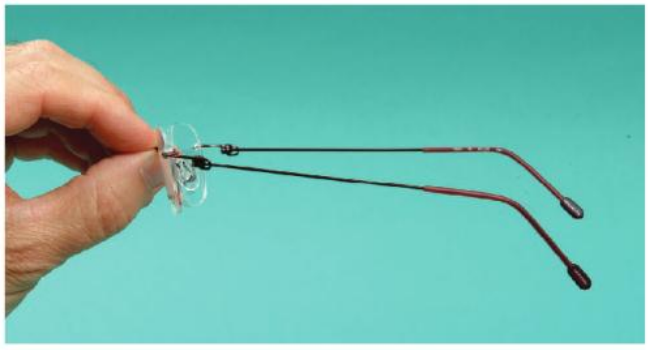


Figure 8.73 The temples of this rimless drill mount are not parallel. The difference in the two pantoscopic angles will cause the frame to fail the flat surface touch test.

that the pantoscopic angle of the temple is increased or decreased, causing the temple to move down or up.

Using rimless bracing and endpiece angling pliers. This method is the same as the one above with one difference. Instead of double-padded pliers, endpiece angling pliers are used to grasp the top and bottom of the temple screw (Figure 8.75). The endpiece angling pliers are rotated, bending the endpiece and moving the temple upward or downward. Endpiece angling pliers tend to hold the hinge area more securely then double-padded pliers.

Bending the temple by hand. It is possible to hold the lens at the temporal point of attachment and bend the temple upward or downward by hand as shown in Figure 8.76. This is probably the least satisfactory method because it is not as easy to control the place where the frame is bent. Using two sets of pliers assures that the bend takes place between the locations of the two pliers.

Aligning the Temple Ends

Procedures used to align the bent-down portion of the temple for skull temples on a rimless mounting are the same as outlined for metal frames.

Cable temples are best aligned using the hands alone. Cable temples must be bent much farther than other temples because they tend to spring back to where they were before.

Temple-Fold Angle

The temples, when folded, should meet the same requirements as described for plastic and metal frames. The same general adjustment routine is followed as for plastic and metal frames except that the point of attachment to the lens must be held with rimless bracing pliers to prevent undo stress on the lenses and their points of attachment.

Fold the temples to a closed position, and look at how they cross one another. They should preferably overlap or at least cross at the center of

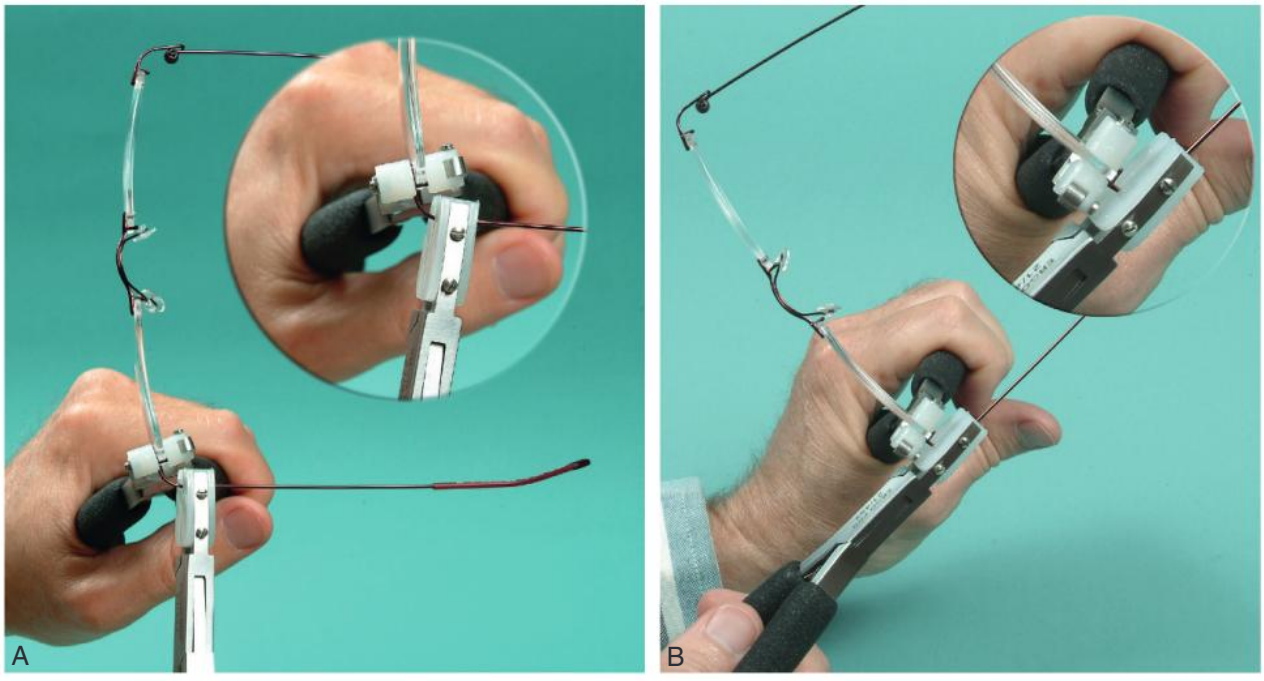


Figure 8.74 **A,** To correct for unequal pantoscopic angles, the dispenser grasps the lens at the temporal mounting point with the rimless bracing pliers and rotates the temple with double-padded pliers. **B,** This method of grasping the endpiece of a rimless mounting is just a variation of that shown in **A.** The temple is still rotated upward or downward.

Figure 8.75 A very popular variation on changing the pantoscopic angle uses endpiece angling pliers to angle the temple.

Figure 8.76 A quick alternative for changing the temple's pantoscopic angle uses rimless bracing pliers to hold and makes the bend with the free hand.

Figure 8.77 A rimless mounting with unequal temple-fold angles.

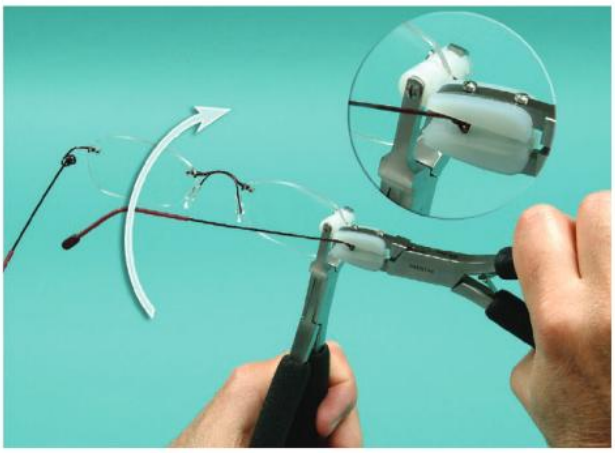


Figure 8.78 Holding the temporal mounting point of the lens, angle the temple with either double-padded pliers, as shown here or endpiece angling pliers.

the frame. Figure 8.77 shows a rimless mounting with uneven temple-fold angles.

To correct the temple-fold angle, grasp the temporal point of attachment with rimless bracing pliers and the endpiece and butt portion of the closed temple with double-padded or endpiece angling pliers. Angle the temple upward or downward with the pliers as shown in Figure 8.78.

OTHER RIMLESS ADJUSTMENTS

Rimless Nose Pad Alignment

The nose pads of rimless mountings should meet the same specifications laid down for metal frames. The chief distinction in technique is that the bending of the pad arms should not be attempted unless the base of the pad arm is sufficiently supported to prevent stress on the mounting point and lens.

This support can be given by holding the mounting point with rimless bracing pliers while adjusting the pads with pad-adjusting pliers. Sometimes it may be enough to support the lens mounting point by holding the mounting point tightly between the thumb and forefinger.

A Loose Lens

A drilled rimless lens may loosen if the lenses are held in place with screws and the screw is not tightened down sufficiently. Screws are often replaced with other brand-specific types of lens attachments. The frame manufacturer should be consulted for specifics.

If the rimless design uses screws and the fault lies with the *screw*, it simply needs to be tightened. The screw may be tightened using an optical screwdriver. However, care must to taken not to slip off the screw and scratch the lens. There is a type of screwdriver with a sleeve

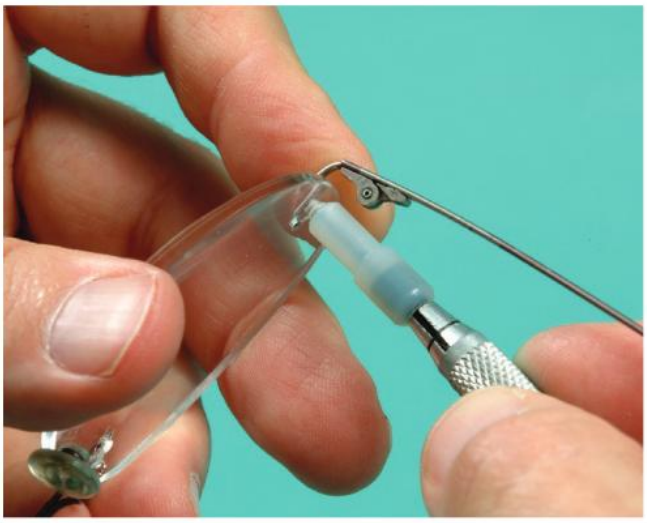


Figure 8.79 A screwdriver made especially for rimless lens screws. The plastic sleeve stabilizes the screwdriver and lessens the risk of slipping off the screw and scratching the lens.

around the blade that helps to stabilize the screwdriver and keep it from slipping onto the lens surface (Figure 8.79). Keep in mind that an overtight screw may crack the lens. A lens screw used for a rimless lens is sometimes referred to as a *glass screw* because, in former days, the screw went through glass lens material.

Some find it helpful to protect the surface of the lens by placing several layers of transparent tape over the lens surface so that if the screwdriver slips, it is less likely to damage the lens surface. If the tape leaves a residue, remove it with alcohol.[3]

REFERENCES

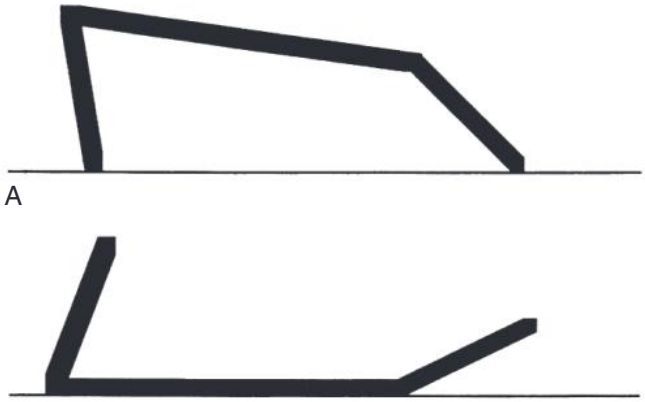
1. Contributed by Dr. Michelle Chen.
2. Tri-Angling Plier, Western Optical Supply, Inc., Santa Fe, New Mexico.
3. Carlton J. Fitting tip: Scotch tape to the rescue. *Optical Dispensing News*. 2003. no 139, June 25.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. True or false? *Truing* means the same thing as *standard alignment.*
   a. True
   b. False
2. True or false? It is safer to use hot salt to heat frames than hot air.
   a. True
   b. False
3. When the frame front is tested for four-point touch but only touches on the two temporal eyewires, the frame:
   a. is skewed.
   b. has face form.
   c. is out of coplanar alignment.
   d. has X-ing.
   e. none of the above.
4. A rotated lens can be detected:
   a. when checking horizontal alignment.
   b. when checking vertical alignment.
   c. when checking for four-point touch.
   d. when checking for equality of pantoscopic angle.
5. A situation in which the frame bridge is somewhat twisted, causing the planes of the two lenses to be out of line, or angled, with each other, is called:
   a. twisting.
   b. a skewed bridge.
   c. X-ing.
   d. wraparound.
   e. none of the above.
6. An error in standard alignment in which, when viewed from the front, one lens appears to be somewhat higher than the other is called:
   a. X-ing.
   b. propeller effect.
   c. wraparound.
   d. lens out of coplanar alignment.
   e. skewed bridge.
7. When one lens is farther forward than the other, the frame:
   a. has a skewed bridge.
   b. has too much face form.
   c. has X-ing.
   d. is out of coplanar alignment.
8. The temples of a frame do not open far enough. The dispenser standard aligning the frame does not know how wide the wearer's head is. Therefore, when putting the frame in standard alignment, it is not a good idea to spread the temples to more than how many degrees?
   a. 85 degrees (with reference to the frame front).
   b. 90 degrees (with reference to the frame front).
   c. 95 degrees (with reference to the frame front).
   d. 100 degrees (with reference to the frame front).
   e. The degree spread is not important as long as both temples are spread equally.
9. To increase the temple spread for standard plastic frames, one should first try to spread the temple by heating the endpiece and bending it outward. If this and all other measures fail, then it is possible to increase the temple spread by filing. To do this:
   a. file the frame front only.
   b. file the temple butt only.
   c. file both front and temple evenly.
   d. file temple butt first and then the front, but file the front only after reaching the metal piece in the temple.
10. When filing temples on a plastic frame, filing the metal piece (a part of the hinge) in the temple:
    a. is permissible.
    b. should be avoided because it decreases the holding power of the temples.
    c. never comes into question because the metal never comes back that far in the temple.
    d. none of the above.
11. (Indicate which of the following responses are false.) A frame's inability to meet the flat surface touch test could be caused by:
    a. the lens not being all the way in the groove, causing the endpiece not to be straight.
    b. broken or loose hinge rivets.
    c. an upward or downward bend in the temple shaft.
    d. a bent hinge.
    e. All of the above responses are true. None of them are false.

12. When checking for equality of pantoscopic angle in the standard alignment process using a table top, which way should glasses be placed on the table as shown in the figure below?
    a. Right side up
    b. Upside down



13. Suppose the bent-down portion of one temple is bent down more than the other. The frames are placed on a table right side up as in figure A.
    a. When viewed in this way, the dispenser may be led to believe that the left and right pantoscopic angles are unequal even if they are not.
    b. When viewed in this way, the left and right pantoscopic angles will appear unequal. This is a sure indication that pantoscopic angles really are unequal and so temple parallelism is absent.
14. One should not use heat in adjusting a conventional plastic frame when:
    a. bending the endpieces.
    b. changing the bridge area.
    c. changing the pantoscopic angle.
    d. bending the temple earpiece.
    e. one should always use heat when adjusting a plastic frame.
15. Of all the tools listed below, which could be a good choice for changing the temple-fold angle of plastic frames?
    a. cutting pliers
    b. a zyl file
    c. half-padded pliers
    d. square-round pliers
    e. finger-piece pliers
16. True or false? Changing the temple-fold angles should not appreciably alter the previously adjusted pantoscopic angles.
    a. True
    b. False
17. True or false? When fully opened, the angle that the temple forms with the frame front is called the *let-back*.
    a. True
    b. False
18. Suppose the temples of a plastic frame, when fully opened, do not open wide enough. This problem may be corrected in one of several ways. Which is not a possible solution to this problem?
    a. The lens may not be completely inserted into the frame groove at the location of the endpiece. Heat the frame and insert the lens completely.
    b. Heat and bend the endpiece outward.
    c. File the butt end of the temple.
    d. Heat the butt end of the temple, and bend the temple outward.
    e. Use a soldering iron or Hot Fingers unit, and heat the hidden hinge so that it will sink deeper into the frame front.
19. When is *retroscopic tilt* manifested?
    a. When the top of the frame front is closer to the wearer's face plane than the bottom of the frame front.
    b. When the bottom of the frame front is closer to the wearer's face plane than the top of the frame front.
    c. When one lens is closer to the wearer's face plane than the other lens.
    d. When one lens is higher on the wearer's face than the other lens.
20. True or false? In standard alignment, the temple-fold angle is not correct until both temples are parallel, even if the temples cross in the center of the frame.
    a. True
    b. False
21. True or false? When reducing temple spread on metal frames, a method that would never work is to push the outside of the endpiece against a flat surface.
    a. True
    b. False
22. Identify the angle illustrated.

    a. nasal angle
    b. vertical angle
    c. retroscopic angle
    d. frontal angle
    e. apical angle
23. Which nose pad angle is best viewed from the top or bottom of the frame?
    a. Frontal
    b. Splay
    c. Vertical
24. Which nose pad angle is most closely related to the pantoscopic angle?
    a. Frontal
    b. Splay
    c. Vertical
25. Which nose pad angle disappears when the nose pads are round instead of elongated?
    a. Frontal
    b. Splay
    c. Vertical
    d. None of the nose pad angles disappear.
    e. With round pads, none of the nose pad angles matter.
26. On an adjustable pad bridge frame, the tops of the two nose pads should normally be closer together than the bottoms of the two nose pads. If this is not the situation but instead the bottoms of the pads are closer together than the tops, which nose pad angle is off?
    a. Frontal
    b. Splay
    c. Vertical
    d. Cannot tell from the information given

27. In standard alignment, the distance of the face of the pad from the nasal eyewire of the frame is normally how many millimeters?
    a. 0 mm
    b. 1 mm
    c. 2 mm
    d. 2.5 mm
    e. 3 mm
28. Pad-adjusting pliers
    a. grip the pad arm behind the pad
    b. grip the face of the pad and the back of the pad
29. When remembering nose pad angles in a humorous way, which pad angle corresponds to the angle mimicked by a chicken flapping its wings?
    a. Frontal
    b. Splay
    c. Vertical
30. Where should a four-point touch be checked on rimless spectacles? (Choose the best single answer from the choices given.)
    a. below the nose pads on the backs of the lenses
    b. above the nose pads on the backs of the lenses
    c. both above and below the nose pads on the backs of the lenses
    d. at the level of the pad arm attachments on the fronts of the lenses
    e. at the level of the pad arm attachments on the backs of the lenses
31. When checking the four-point touch in a rimless mounting, it is found that the straight edge contacts the four proper points above the nose pads, but below the nose pads, the straight edge only touches the left lens and not the right. What error has occurred?
    a. too much face form
    b. too little face form
    c. lenses out of coplanar alignment
    d. horizontal misalignment
    e. X-ing
32. Of the lens materials listed, which material is least likely to break, crack, or develop stress splits at the mounting point when used for rimless drill mountings?
    a. CR-39
    b. Polycarbonate
    c. Trivex
33. The use of two pairs of pliers at one time is most likely to be of benefit with which type of frames?
    a. Cellulose acetate plastic
    b. Metal frames
    c. Rimless mountings
    d. There is no difference

9

Adjusting the Frame

CAUSES OF COMPLAINT

The role of the physical features of a pair of spectacles and how well they are fit to the individual is crucial to satisfaction and the ability of the individual to adapt to the new prescription. Kintner,[1] in his classic study of the relative role of the physical features serving as factors affecting the wearing comfort of spectacles, concluded that the overwhelming majority of complaints were related to the fit of the frames—a direct result of the frame selection and spectacle adjustment. Many wearers seem more likely to tolerate spectacles in which the prescriptions are slightly awry if the frames fit comfortably. A wearer is not as likely to tolerate spectacles if the frames fit poorly even if the prescription is correct.

The comfort and suitability of the fitting seem to be the most significant criteria for satisfaction.

OVERALL FRAME ADJUSTING

THE FITTING PROCESS

A new frame should be in standard alignment (refer to Chapter 8) when it is received by the fitter. As discussed in the previous chapter, however, this is not always the case, so it is wise to check the frames and put them into standard alignment, if necessary, before attempting to adjust them to the wearer's face.

All rules applying to the fitting of new frames for a first dispensing will also apply to the readjustment of frames that have been worn over a period of time and have come out of alignment.

Putting the Frames On

It is preferable to begin the fitting procedure by having the fitter put the frame on the wearer's face for the first time. If the frame requires a good deal of additional adjustment, the fitter should recognize this and remove the frame immediately so that the wearer does not become falsely concerned that the glasses may not be right for him or her.

To place the spectacles on the wearer, hold them by the temples, pulling slightly outward to facilitate slipping the glasses on easily, and guide the ends of the temples just over the ears and down (Figure 9.1). If the temples must be spread a great deal to get them on, use one of the methods outlined in Chapter 8 to adjust the temple spread. This will allow the temples to open wide enough to permit the frame to rest on the nose without pressure against the side of the head.

Triangles of Force

The fitting triangle described by Stimson[2] is composed of the three points where the spectacles contact or put pressure against the head. The apex of the triangle is the contact point on the crest of the nose, and the endpoints of the base of the triangle are the two pressure points just above the roots of the ears, one on each side of the head (Figure 9.2). Since pads are often used for frames, there may be two resting points to the apex of the triangle.

Achieving the Proper Temple Spread

The temple-spread angle of the frame should be such that the shafts of the temples exert no pressure, even if touching, on any area of the face or temple before the point of the head at which they should exert pressure—*just above the root of the ears*. This position is usually the widest portion of the head.

Temples Not Spread Enough

If the temples are not spread far enough, there will be too much pressure on both sides of the head, causing the temples to bow out (Figure 9.3). This forces the frame forward until the temples are opposite to a narrower part of the head. When the frame slides forward, the pressure that tends to bend them is somewhat relieved (Figure 9.4).

If the glasses are fitted in this manner and the temple spread is never corrected, the glasses will not only tend to slide down, but as they do so, the bent-down portions of the temples will pull against the backs of the ears. Then, not only do the glasses slip down as if they were loose, but they hurt behind the ears as well. The wearer experiences the disadvantages of both loose and tight glasses at the same time.

The first step in the entire adjustment procedure is to achieve the temple-spread angle that permits the front to rest easily on the nose without being forced forward. This is done by adjusting the endpieces so that the temples do not exert pressure against the sides of the head at any point in front of the ears. The temple shafts may touch the sides of the head but should not exert pressure. The adjustment should be such that the corner of a sheet of paper may be slipped between the temple shaft and the side of the head. The only place where pressure is allowable is above the root of the ears.

If the head is very round or is wider in front of the ears than above the ears, it may be necessary to bend the temples into an arc that follows this wider portion of the head but eventually presses the head immediately above the root of the ear.

Temples Spread Too Far

If the temple-spread angle is too wide for the patient's head, the glasses will tend to slide down the nose. More often, this occurs if the frame has been worn for some time. The specific methods used to reduce the temple-spread angle can be found in Chapter 8.

Equality of Lens Vertex Distance

At this point, it is advisable to check the glasses for equality of vertex distance. This is done by having the wearer tilt his head forward while the dispenser views the glasses from above (Figure 9.5). If the glasses have been properly aligned and the wearer's head is symmetrical, both lenses will be the same distance from the wearer's face. If, however, the temple spread is unequal with one temple angling farther in or out than

Figure 9.1 The fitter holds the spectacles by the temples, spreading them a bit more than their resting position to avoid having the wearer feel that they are being forced onto the head.

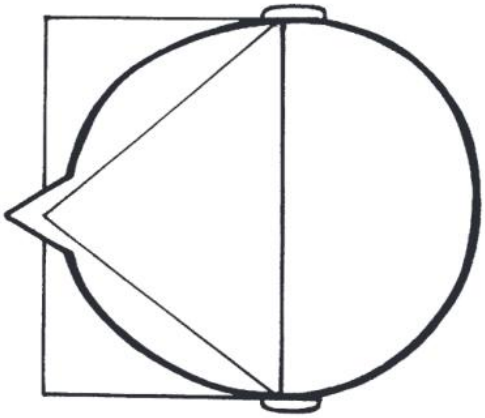


Figure 9.2 The fitting triangle is the connection of only three points upon which "pressure" may be exerted. These are the crest of the nose and the sides of the head just above the roots of the ears. The pressure on the nose is from the weight of the frame.

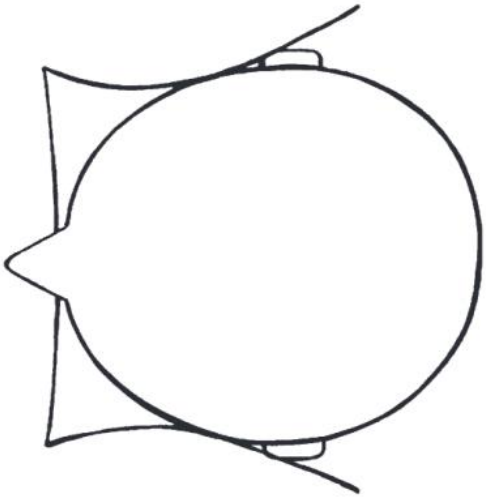


Figure 9.3 Even though the illustration is exaggerated, it can be seen how pressure is exerted on the head and that a negative bow in the temples is created.

the other, or if one side of the wearer's head is somewhat wider than the other, one lens will be closer to the face than the other.

The necessary correcting procedures for this inequality will be directly indicated by the way the frame positions itself. If, as in Figure 9.5 where the wearer's right lens is farther from the face, there

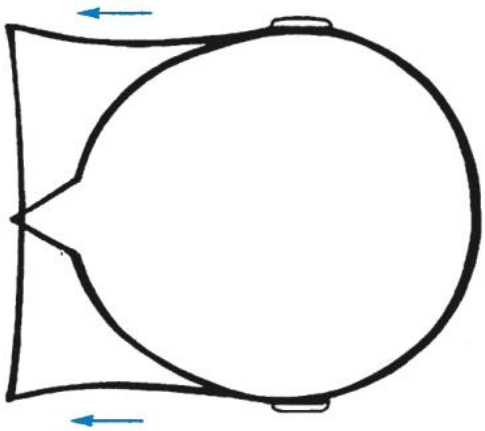


Figure 9.4 In an attempt to return to their original shape, the temples cause the glasses to slip. This creates a situation with the worst characteristics of both tight- and loose-fitting glasses. Not only do the glasses slip forward, but they may also hurt behind the ears.

Figure 9.5 The lens in front of the wearer's left eye is closer because one temple is pressing harder on one side of the head than on the other.

is more pressure over the wearer's right ear than the left, then the right side will be forced out. (The principle is the same as was described in Figure 9.4 except that one temple is under more stress than its partner, forcing that side forward.) The remedy to the problem can be approached in two ways.

1. It may be that the right temple is not spread far enough, making this side fit too tight. The solution is to open the temple out farther. This is done in the same manner as for standard alignment.
2. It could also be that the right temple is correctly fitted, but the left temple is too loose. The right only has the *effect* of pushing its side forward because of the lack of counteracting pressure on the left side. Here, the solution is to bring this left temple inward, decreasing the spread. Again, the techniques used are the same as those described for standard alignment of the frame.

In practice, often both temples are adjusted somewhat, one being brought in and the other opened out. As stated before, regardless of whether the problem lies with the glasses or the head shape, the solution is the same and is indicated by the way the frame positions itself. Table 9.1 presents a simple way to remember these adjustments.

If the glasses are dispensed incorrectly, with one temple not spread sufficiently, then, after being worn for some time, the ear on this same side *and* the opposite side of the wearer's nose will become sore. This results from the clothes-pin-like effect of the tighter side of the frame

TABLE 9.1 To Move One Lens Closer to the Face (IN With IN, OUT With OUT)

Problem	Solution
If left lens is IN (and) If right lens is OUT	Bring left temple IN or Bring right temple OUT
If right lens is IN (and) If left lens is OUT	Bring right temple IN or Bring left temple OUT

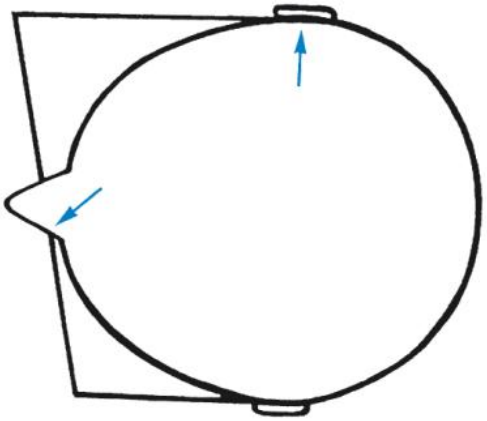


Figure 9.6 If the wearer complains of the frame hurting one side of the nose, unequal temple-spread angles might be suspected, especially when the back of the ear on the opposite side hurts, too.

pinching the face (Figure 9.6). Therefore, if a person complains of the frame hurting one side of the nose, an improper temple-spread angle might be suspected.

It should be noted that, in approaching the problem of vertex distance inequality, it is a good idea to first check to see if one of the temples is not straight but bowed in or out. If the temple is bowed or bent, straighten it first. A single bowed temple can cause a vertex distance inequality in the same way as differences in temple-spread angles do.

THE FRONT

The adjustment of the frame front takes place *after* making certain the temple-spread angles are right. Here is the two-step overview:

- First, adjust the frame so that the frame front has a proper pantoscopic angle or tilt as viewed from the side.
- Next, adjust the frame so that it is straight on the face when viewed from the front.

A proper pantoscopic angle and frame straightness should precede any nose pad adjustments. This is because changes in the angle of the frame front will directly affect how the nose pads rest on the nose. If the nose pads are adjusted so they sit flat on the nose first, and then the whole frame front is re-angled for a new pantoscopic angle, then the pads will no longer be sitting flat on the nose.

Pantoscopic Angles

The usual tilt of the frame front may be anywhere from 4 to 18 degrees from the vertical. It will only approach the upper (18-degree) extreme in the case of exceptionally protruding eyebrows. In evaluating the pantoscopic angle, the lenses or rims of the frames should touch neither the brows nor the cheeks.

(The optical reasons for varying amounts of pantoscopic tilt were described in Chapter 5.)

Straightness of the Frame on the Face

If the frame is crooked on the face, adjustment of the pantoscopic angle at each endpiece will allow the frame to be leveled when viewed from the front.

The first possible cause of a crooked frame is incomplete standard alignment. If the temples are not parallel and fail the flat surface touch test, then the frames cannot be expected to sit straight on the face. However, even if the temples are parallel, there may still be a problem.

Most heads are not symmetrical. One ear is often slightly higher than the other. In such instances, even previously standard-aligned glasses with temples parallel will appear tilted on the face when viewed from the front.

The solution is the same whether the cause is the frame or the face. The pantoscopic tilt* (or, more concisely, the angle the temple makes with the frame front) needs to be changed on one or both sides.

If the right side of the frame is too high, the right temple must be angled up. Angling the temple up allows the frame to drop down farther on that side before it contacts the top of the ear.

Even though this will cause the frame to be straight, it may not be advisable to decrease the pantoscopic angle on the higher side. Sometimes this will cause the frame front to have too little pantoscopic tilt when viewed from the side. If this is the case, angle the opposite temple down instead. This increase in the pantoscopic tilt of the opposite side accomplishes the same result by raising the side that is too low.

Often, both raising one temple and lowering the other are required. One bend alone may be insufficient to level the frame. Stated simply, if the right side of the frame front is up, bend the right temple up, or, looking at it from the other side, if the left side is down, bend the left temple down. Table 9.2 shows this in an easy-to-memorize chart.

When the ears are at unequal heights on the head, changing the pantoscopic angle to straighten the glasses on the face will cause the glasses themselves to lie crooked when placed on a flat surface. If this is not pointed out to the wearer, he or she may think the glasses are in error and be suspicious of the quality of the fitting. *Always call this to the wearer's attention.*

*Note: At this point it would be helpful to remember that the term *"pantoscopic angle"* could mean two different things, depending upon whether the frame is being standard aligned or adjusted to fit the wearer's face. The definition of pantoscopic angle that relates to fitting is "the angle that the frame front makes with the frontal plane of the wearer's face when the lower rims are closer to the face than the upper rims" (see Glossary). However, during the standard alignment process, pantoscopic angle refers to "that angle by which the frame front deviates from the vertical … when the spectacles are held with the temple horizontal."

TABLE 9.2 To Move One Lens Higher on the Face (UP With UP, DOWN With DOWN)

Problem		Solution
If left lens is UP		Bend left temple UP
(and)	or / or	
If right lens is DOWN		Bend right temple DOWN
If right lens is UP		Bend right temple UP
(and)	or / or	
If left lens is DOWN		Bend left temple DOWN

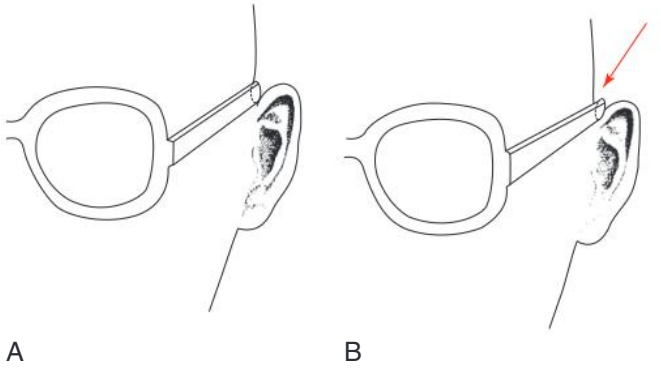


Figure 9.7 A library or skull temple should be adjusted so that the whole side of the temple is parallel to the slope of the head above the root of the ear. **A,** Proper parallel fit. **B,** Not parallel. Notice that just above the ear, the top of the temple angles out and away from the side of the head.

Other Sources of Error Causing the Frame Front to Appear Crooked

When the glasses are crooked, the following areas should also be checked in determining the source of error.

1. Is one of the temple shafts bent?
2. Is the bridge skewed?
3. Is one ear farther back than the other? If the temples are the same length, this will cause the bent-down portion of the temple on the side where the ear is farther back on the head to strike the ear at a different position than the other. This results in the same effect as one ear being higher.

Reference Points

Although it is helpful to refer to the eyebrows when determining the level of the frame, facial asymmetry can cause one lens to appear higher than the other even when this is not really the case. The frame front should not be aligned solely on the basis of eyebrow height or the position of the eyes in the head because either of these features may be asymmetrical. Instead, overall appearance of both eyes and brows should be used. If, due to facial asymmetry, the frame conforms better to facial features when fitted slightly higher on one side, then it should be fit that way.

If bifocals are being dispensed and have been correctly measured using a properly adjusted frame for each eye independently, the logical reference point is the relationship between the bifocal line and the lower edge of the pupil. To judge this objectively, tilt the wearer's head back and note whether or not both segment lines intersect the pupils at the same point. (For a more complete description of both objective and subjective techniques, see Chapter 5.) The same may be said for the fitting cross markings of progressive addition lenses. Fitting crosses should be centrally positioned before the pupils. Because of this, it should be clear why the frame that will be used (or the sample frame) should be adjusted for height and straightness *before* segment or fitting cross heights are measured and ordered.

THE TEMPLES

When all adjustments having to do with the front of the glasses have been done—open temple angle, pantoscopic angle, height, vertex distance, and pad positions on the nose—final attention is paid to the adjustment of the temples.

If the previous adjustments are satisfactory, the spectacles will stay in proper position on the face *if the head is held erect* even though the temples are not fully adjusted. This is true as long as the first point of contact of the temples is at the sides of the head just above the ears. *(Note: This is the correct time to adjust the nose pads. We have not yet covered nose pads. If the frame does have nose pads, they need to be adjusted before the ends of the temples are adjusted. Nose pads are covered in Fitting Adjustable Nose Pads of this chapter.)*

Lateral pressure—The pressure of the temples against the sides of the head just above the ears is increased, if necessary, by decreasing the temple spread. This can be done by any of the methods described in Chapter 8, such as bending the endpiece areas in.

The correct amount of lateral pressure is such that the patient feels no pressure or, if pressure is felt, no discomfort. The glasses should stay firmly in place even if the head is lowered. This should be true even though the backs of the temples have not as yet been adjusted.

An important point to remember in fitting temples is that the best way the glasses are held in place is with friction, not pressure. Friction is increased when the area contacting the side of the head is maximized. With that in mind, adjustment of any type of library or skull temple will work best if the inside of the temple is parallel to the head in three places: (1) along the temple shaft, (2) above the root of the ear (Figure 9.7), and (3) along the slope of the head behind the ear.

This may require rotating the temple about its long axis. To do this, heat and twist the temple.

Earpiece or curl—When the lateral pressure is satisfactorily applied, attention is given to that portion of the temple that lies past the top of the ear. Adjustment varies depending on the type of temple used and will be considered according to temple type.

Fitting Straight-Back and Skull Temples

A straight-back, or library, temple has no vertical bend behind the ear. As the name implies, it goes straight back. A skull temple is bent down behind the ear.

Many temples can be fit with or without a bend at the ear as either a skull or a straight-back temple. To begin with, we will consider how to fit a temple without a bend. In doing so, we can consider first the way the temple fits against the side of the head. Later we can add the bend.

All the principles applying to a straight-back, or library, temple also apply to the skull temple.

Adjustment of straight-back temples consists of bending that portion of the temple that lies just past the top of the ear inward. This is done in such a way that the inside surface of the temple lies fully against the portion of the head directly behind the top of the ear.

The temple must contact the head continuously from the top of the ear back, exerting uniform pressure all along that area.

A common error used to tighten up a frame that slides down the nose is to bend the whole temple into an arc or to bend the very last portion of the temple too far inward. The result is that the end of the temple exerts excessive pressure at a single point on the head. This maladjustment usually bows the rest of the temple away from the head (Figure 9.8). At first, the wearer is happy because the glasses no longer slide down the nose, but the inward bend of the temple displaces the upper lobe of the ear and eventually digs a painful pit into the side of the head where the tip presses against it (Figure 9.9). This all too common error is seen with both straight-back and skull temples.

When bent inward too far, the excessive pressure of the tips against the head causes the endpieces and the bridge to give, bending outward. This, in turn, eventually releases the lateral pressure that holds up the frame. For the inexperienced fitter unaware of the source of error, the erroneous "remedy" is usually more of the same. This means increasing the temple arc to restore the tip's contact against the side of the head. A vicious circle occurs, resulting in widely bowed temples and an excessively bent frame front (Figure 9.10).

If the structure of the skull is such that there is a dip or hollowed-out convolution in the side of the head, heat the temple and bend it to follow the side of the head as precisely as possible. The objective is to establish as much friction through contact of the surfaces as possible so that a "disc brake" action is introduced. The dispenser may heat and press an indentation into the bent-down portion of a skull temple with both thumbs. Because of this, many call this "adding a thumbprint" to the temple. If this is too difficult to do with the thumbs, eyewire forming pliers can be used as shown in Figure 9.11. (These pliers were pictured earlier and are normally used to shape the eyewire of a metal frame as is seen in Figures 7.14 and 7.15.)

If the frame front has been properly adjusted, the lateral temple pressure correctly applied, and the friction contact of the temple ends well established, then the spectacles will remain secure without hurting.

Positioning the Temple Bend

The proper position of the bend in the temple lies just *past* the top of the ear. The downward slant of the earpiece should parallel the slope of the back of the root of the ear. If it even touches the root of the ear, it should just barely touch it (Figure 9.12). Above all, the temple must not press into the crease between ear and head or on the small cord of cartilage that helps in connecting the ear to the head (Figure 9.13).

The earpiece portion of the temple should not be just bent down (Figure 9.14). It must be positioned against the side of the head, usually requiring inward angling.

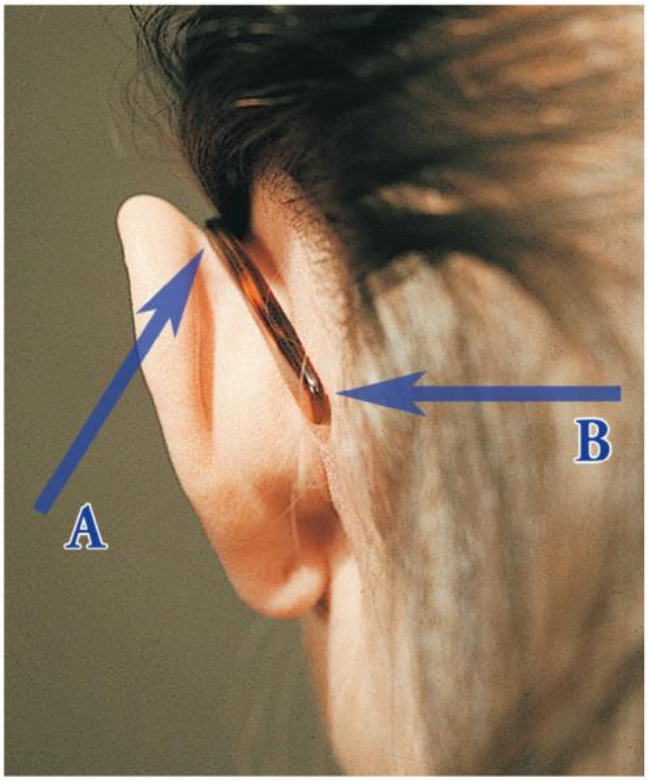


Figure 9.9 The error in Figure 9.8 is shown in this photo of a skull temple. Note how the temple presses both outward on the lobe of the ear (*arrow A*) and inward against the side of the head (*arrow B*).

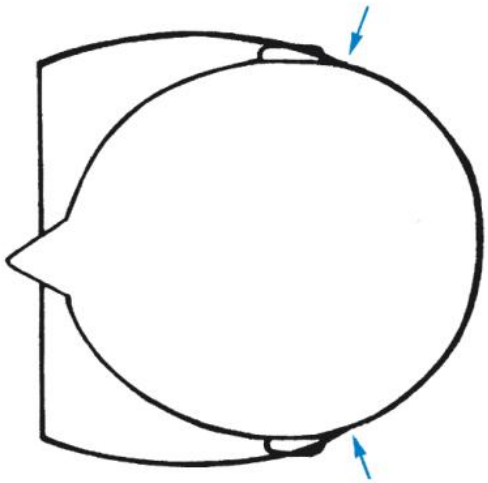


Figure 9.8 A common dispensing error committed by an untrained fitter is that of bowing the temples to achieve a snug fit.

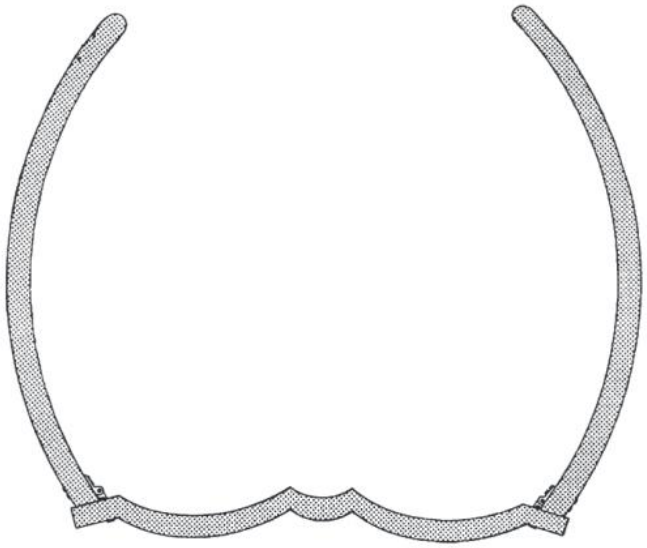


Figure 9.10 Pressure created by bowing the temples is transferred to frame bridge and endpiece areas, causing them to give over a period of time. The illustration shown is a natural outcome of continually increasing temple bowing to maintain a snug fit.

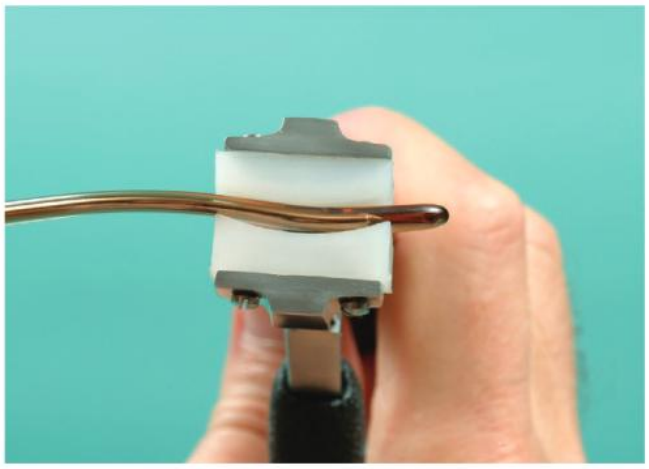


Figure 9.11 The end of this temple is being shaped to conform to a slight hollow in the side of the wearer's head. This dip in the temple is often referred to as a "thumbprint" because it may be pressed into the temple using both thumbs. Here, it is being pressed into the temple using eyewire-forming pliers.

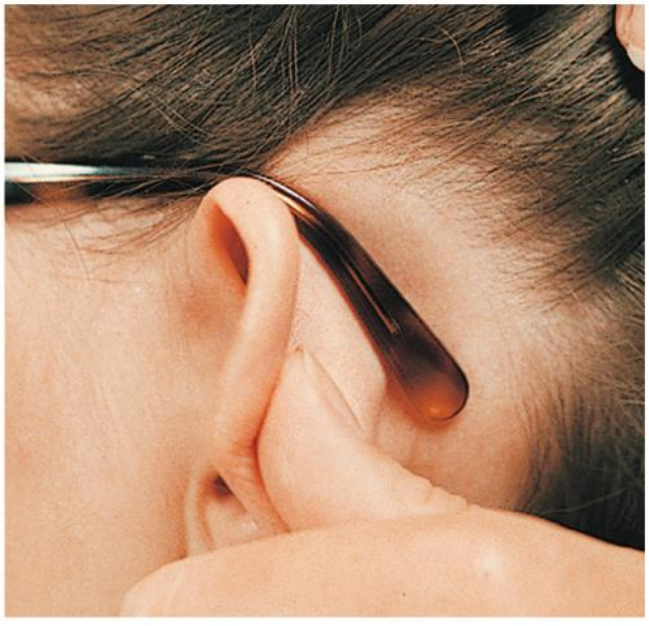


Figure 9.12 A properly positioned temple bend occurs just behind the top of the ear. This allows the bent-down portion of the temple to parallel the upper root of the ear.

Shape the descending earpiece portion to match the convolutions of the mastoid process, which is a lump on the side of the head behind the ear. It should exert even pressure throughout its length, just as with the straight-temple types.

Temples Too Long or Too Short

If the temples are too long or too short, the position of the temple bend can be modified. There are, of course, limits as to how far the bend can be moved because too radical a change will result in the earpiece being too long or too short. A change of the bend position is more easily and satisfactorily performed for plastic temples than for temples made entirely from metal. Some metal temples may need to be replaced by properly sized temples. Frames come complete with temple lengths predetermined by frame front size. Keep in mind when selecting the

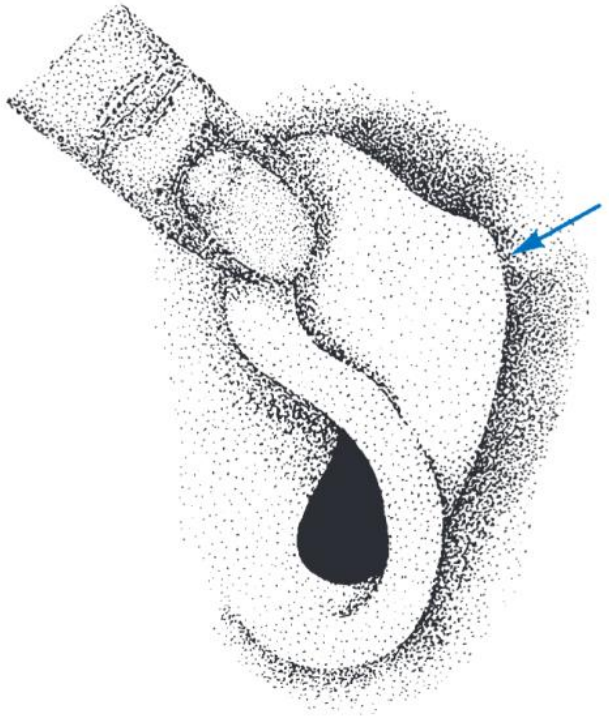


Figure 9.13 With the ear folded forward, the arrow points out the most sensitive portion of the ear. Pressure from the temple on this area should be avoided.

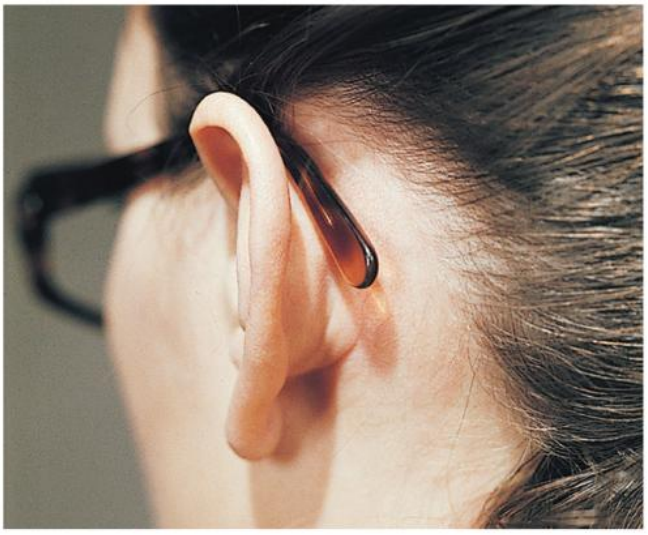


Figure 9.14 Properly positioning the location of the bend is incomplete if the bent-down portion of the temple stands away from the side of the head.

frame that it may not be possible to simply order a different temple length. Every effort should be made to find a frame that is appropriate for both the size of the frame front and temple length.

Since temples are usually manufactured in steps of 5 mm, there is always a possibility that a temple may not fit quite as precisely as desired on a given head. If this is the case, the position of the bend can be changed. The position of the bend also needs to be changed in cases where the correct length is not available. The suggested procedure for changing the position of the bend is as follows:

1. *Note bend position*—The front should be positioned so that the glasses are seated as they will be when worn. Often new glasses or

frame samples fit much too loosely, allowing the glasses to slip down on the nose. When this happens, the temple slips forward until stopped by the ear. As a result, the temple bend appears to be properly situated when, in actuality, the temples are too long. To avoid this problem, grasp the glasses around both endpieces with the left hand. Hold them on the wearer's face where they should actually sit. The right hand is then free to move the hair back or bend the ear forward to inspect for proper fit (Figure 9.15). For the left temple, switch hands and repeat the procedure. It cannot be assumed that both temples will fit the ears correctly just because one does. Faces are not symmetrical; sometimes two separate temple lengths are indicated.

Figure 9.15 The desired location of the temple bend is accurately determined only if the glasses are properly positioned. Error in bend placement is prevented by holding the frame in place.

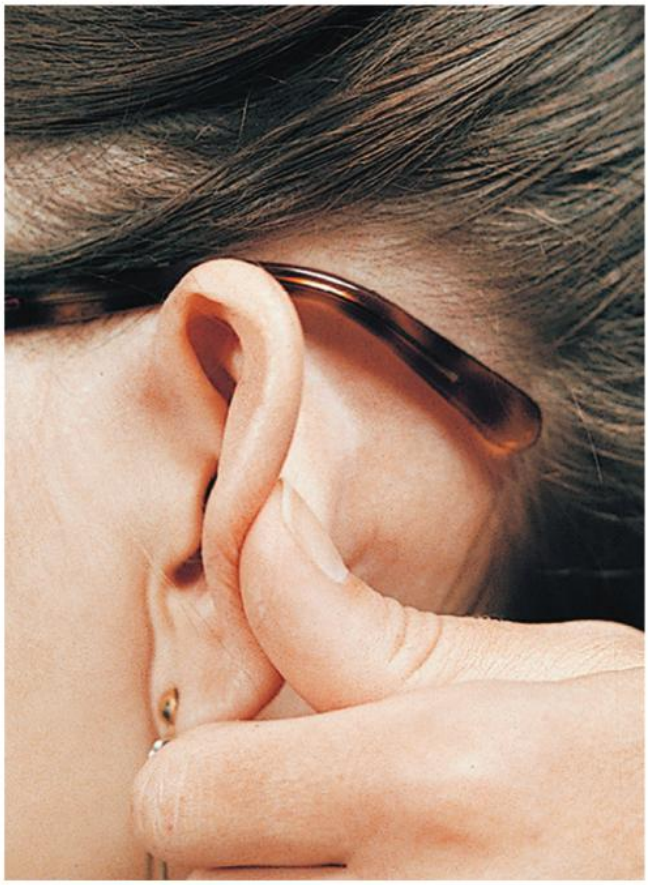


Figure 9.16 If the temple shaft is too long, the bend will occur past the desired position.

If the shaft is *too long* (Figure 9.16), the bend will occur beyond the desired position. The desired position is located just barely past the top of the ear. This permits the spectacles to move forward until the earpiece rests against the cartilage in the back of the ear.

When the temple bend is too far back, it is incorrect to simply increase the angle of the bend in the temple until the bent-down portion touches the back of the ear. The fallacy here is that there are only two points of contact—the top of the ear and the back of the ear—resulting in an extremely painful spot behind the ear after continued wearing. Instead, the position of the bend in the temple should be moved so that the temple fits correctly.

If the shaft is *too short*, the bend will occur forward of the top of the ear, causing the bent-down portion to rest on the posterior slope of the cartilage. This usually raises the temples up off the ear so that the bend itself is visible along the side of the head and the end of the temple pushes against the back of the ear (Figure 9.17).

2. *Estimate new bend position*—Observe the relationship of the bend to the position it should occupy above the ear, and determine a new position for the bend. Observe each ear separately because the two sides of the head and face may not be symmetrical.

   (Note: It may be helpful to pull the outer ear forward and place a ruler so that it parallels the root of the ear between the highest point and the most posterior point of the root of the ear. Now note where the ruler crosses the lower edge of the frame's temple. This crossing point is where the temple bend should be located.)

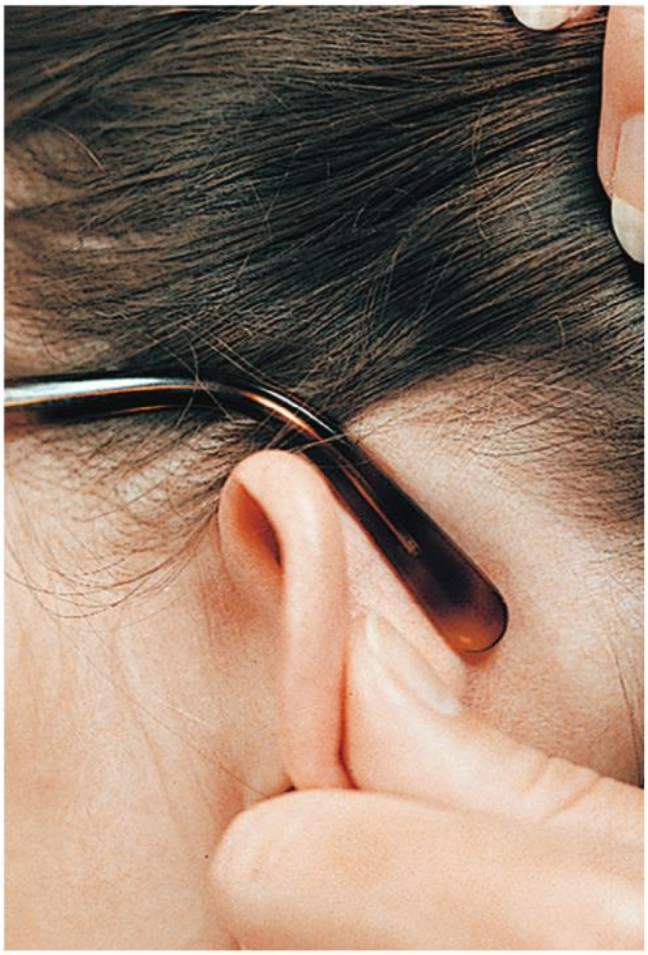


Figure 9.17 If the shaft is too short, the bend will occur too far forward. Note how this raises the temple up off the ear so that the bend itself is visible.

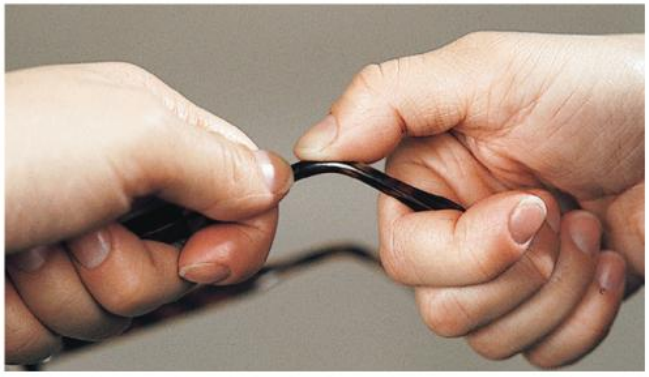


Figure 9.18 Straightening the temple to move the bend to a new location may be done as shown. If the bend is to be moved forward, it may also be done by first placing a new bend at the desired location and then removing the old bend.

Figure 9.19 A well-fitting bend is a sharp bend. Creating a good, sharp bend may be done by forcing the end of the temple over the knuckle.

3. *Straighten and bend, or bend and straighten*—Heat both the original bend area and that portion of the shaft where the new bend is desired. Hold the shaft of the temple firmly in one hand, and grasp the bent portion with the fingers of the other hand with the thumb braced on the bend (Figure 9.18). Pull the end up so that the entire temple is straightened.

Move the fingers of the hand holding the temple shaft so that the temple is braced at the new bend point by the thumb and forefinger. Push the protruding end with the thumb of the other hand until it bends over the forefinger of the holding hand to the desired angle (Figure 9.19).

For some, it may be too difficult to add a new temple bend with the hands alone. There is a pair of pliers that is designed for this use. *Temple bend pliers* may be positioned at the desired location of the temple and the bend added as shown in Figure 9.20. There is also a tool called a *Bionic Thumb* (Figure 9.21).

This enables temple and other frame bends to be made with the hands but without the pain from heat and pressure (Figure 9.22).

Physically Lengthening and Shortening of Temples

Some metal frames come with bent-down portions that have a metal core but a plastic outer portion. These types of temples are unique in that they may be shortened or lengthened beyond what would be expected. It is even conceivable to shorten some plastic temples. Both possibilities are explained in Chapter 10.

Figure 9.20 A temple bend may be added using temple bend pliers. The temple will still need to be heated but should not be overheated to avoid marking the plastic with the pliers.

Figure 9.21 The Bionic Thumb is a device that allows temple bends to be made without as much stress on the hands. It also shields the thumb from a heated temple. (From https://www.hilcovision.com/f/bionic-thumb. Accessed 3/11/2021. Used by permission.)

Summary of Temple Fitting Criteria

In summary, the temples should meet all the following criteria:

- The shaft of the temple should not exert pressure on the face or head at any point in front of the position just above the ears. The point just above the ears should receive the lateral pressure of the temples.
- The bend should be just at the point immediately following the top of the root of the ear so that it does not rest on either the top of the root of the ear or push against the back of the origin of the ear (Figure 9.23).
- The bent-down portion should be angled so that it approximately parallels the posterior descending slope of the root of the ear (crotch of the ear) without pressing into either the crease between the ear and the head or the cord located there.

  A distinct temple bend location is advisable instead of a gradually changing curve. This will allow the bent-down portion of the temple to parallel the root of the ear from the top to the back. This is generally close to a straight line and will allow the bent-down portion of the temple to have contact over a greater distance.
- The cross section of the shaft, if other than round, should be parallel to the slope of the head and lie with its widest part against the head.
- The bent-down portion (earpiece) should slope with its widest part flat against the side of the head. It should be shaped so that it follows the depression behind the ear (the ischium hollow) and the

Figure 9.22 Here is the hand position for when the bend of the temple is either being repositioned or bent further down using the Bionic Thumb. (From https://www.hilcovision.com/f/bionic-thumb. Accessed 3/11/2021. Used by permission.)

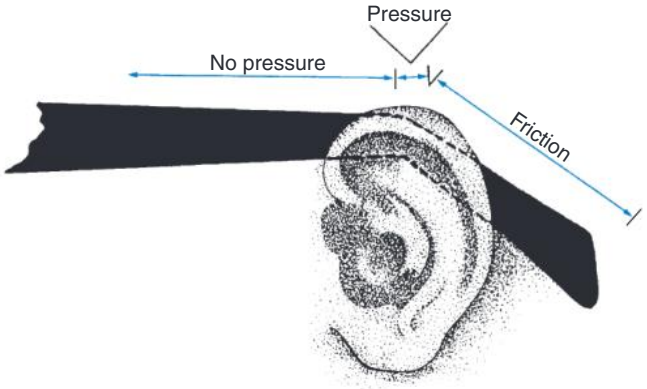


Figure 9.23 The proper location for the temple bend is at the point immediately behind the top of the root of the ear. The only place where pressure is indicated is against the side of the head immediately above the ear. Beyond this point, the hold should be by friction on the order of a disc brake.

elevation following below it known as the *mastoid process*. There should be even pressure throughout the entire area (Figure 9.24). The ends of the temples should not gouge the back of the head or exert greater pressure than the balance of the earpiece.

Spring Hinge Temples

Temples with spring-loaded hinges have been much improved. When spring temples were first introduced, they were much more appealing to the wearer than to the dispenser. Because they did not originally have the strength and resiliency of today's designs, it was necessary to fit them so that they were stretched halfway open when fit. In other words, the midpoint of the tension-spread area would fall at the natural position of the temple when placed on the wearer.

Better engineered spring hinges have changed all that. Now the spring hinge temple is fit in exactly the same manner as any other temple. It should fit on the head so that, under normal wearing circumstances, the spring hinges are not flexed. The advantage of spring temples is not that they hug the head any differently than normal, well-fitted temples; they do not. The advantage of a good quality spring hinge is that it allows the frames to retain their adjustment longer.

Figure 9.24 A temple will be more comfortable and hold the frame in place better if it parallels the anatomical shape of both head and ear.

When people put their glasses on and take them off day after day, there is a certain amount of stress placed on the frames. The temples are forced open beyond the point for which they were adjusted. Eventually, they begin to lose their adjustment. Temples with spring hinges prevent that stress because the spring in the hinge absorbs it.

Frames with spring hinges are less likely to require readjustment or repair when glasses are struck with a ball or an elbow or knocked from the face. This is because, once again, the spring hinge allows the temple angle to bend outward and then rebound rather than to bend and stay bent.

Spring temples are adjusted behind the ears exactly as any other temples. The same rules apply to the position of the temple bend as well.

Riding Bow and Cable Temples

Riding bow or cable temples can be used in situations in which a skull temple will not hold the spectacles adequately, such as for some children, for individuals engaged in rough physical activity, or for wearers with disabilities. Riding bows are made from plastic; cable temples are made from coiled metal.

To fit a cable or riding bow temple, the temple should follow around the root of the ear. The very last few millimeters of the temple should be turned back away from the ear to keep the end from digging in. Figure 9.25 shows the end of the temple before it has been adjusted. The end of the cable should be bent back and slightly away from the side of the head. This is done with double-padded pliers as shown in Figure 9.26. The completed bend is shown in Figure 9.27.

Temple Length

When the necessary cable temple is not on an available sample, the proper length may be estimated by adding 0.75 inches, or approximately 20 mm, to the length of the equivalent, correctly fitting skull temple.

A cable temple of the correct length should stop just short of the lower lobe of the ear (Figure 9.28, *A*). Cable temples that are too short will not have enough length to grip the lower area where it is needed (seeFigure 9.28, *B*). Cable temples fitted too long have a tendency to dig into the lower earlobe (see Figure 9.28, *C*).

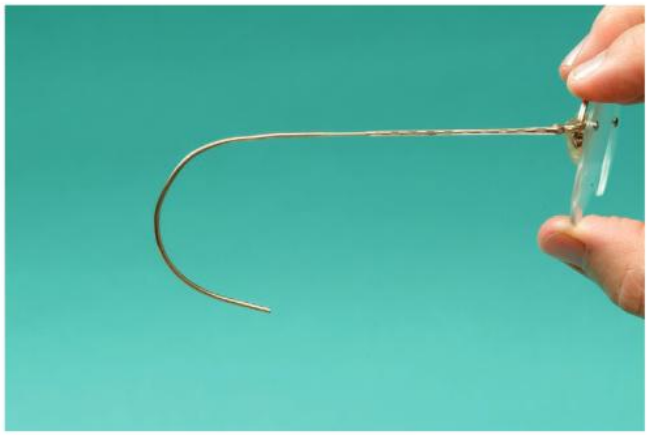


Figure 9.25 Here is what the end of a cable temple looks like before the tip of the temple has been adjusted.

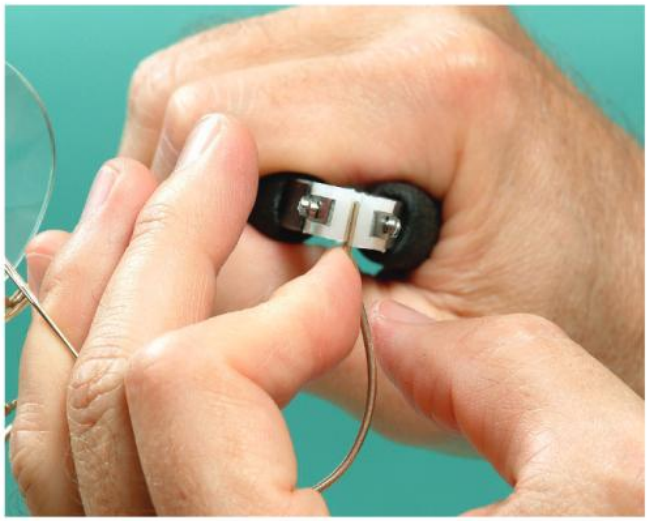


Figure 9.26 The end of the cable temple is bent so that the end will not dig into the crotch of the ear. Hold the temple right next to the double-padded pliers so that the bend will be sharp and well-defined.

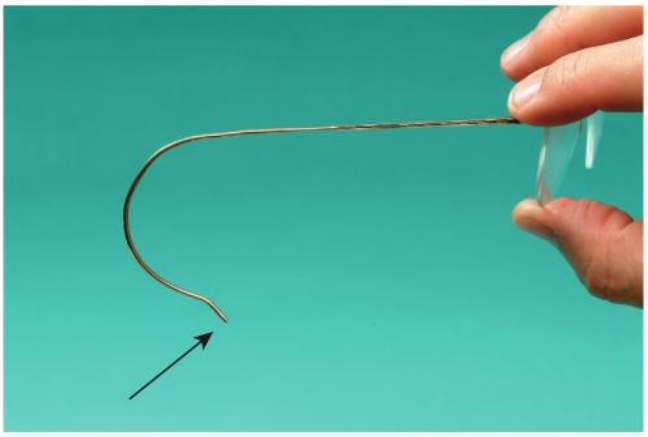


Figure 9.27 Here is what the tip of the cable temple will look like after the bend at the tip is complete.

Hearing Aids and Fitting Eyewear

For a time, some hearing aids were made to fit in the temples of a person's spectacle frames. With the continued development of smaller hearing aids combined with rapidly changing eyeglass frame fashions, in-temple hearing aids are now rare. They do reappear from time to time despite some obvious disadvantages, which include the following:

- In-temple hearing aids limit the person to one pair of glasses.
- When the glasses or aid needs repairing, the wearer is disadvantaged by lacking in both hearing and vision correction.
- Needed replacement of hearing aids or glasses do not occur at the same time.

Most hearing aids fit within or behind and within the ear. In-the-ear aids require no special considerations when fitting and adjusting temples. Hearing aids with a behind-the-ear component work best if the temple style chosen is as thin as possible. Temples must closely follow flush against the side of the head. The thinner the bent-down portion of the temple is, the less will be the interference with the aid.

One of the better choices, although not readily available with a variety of frames, is the cable temple. The cable hugs the base of the ear and is out of the way of the hearing aid. Fortunately, it is usually possible to find an acceptable temple choice without having to use a cable temple. (It should be mentioned that there is a section on converting a skull temple by replacing the end of a skull temple with a cable end in Chapter 10, *Frame Repairs and Modifications.*)

GENERAL INSTRUCTIONS TO THE WEARER ON FRAME HANDLING

There are many different sets of instructions appropriate for different types of wearing situations. Bifocal wearers will be given different advice on use than progressive addition lens wearers. Those instructions and precautions are addressed in the section of the text that covers each particular topic. As for the handling of eyeglasses in general, here are a few suggestions:

1. To keep eyeglasses in adjustment better, glasses are best taken off using two hands.
2. When removing glasses with the right hand only, grasp the right endpiece, lift the right temple off the ear, and move the glasses

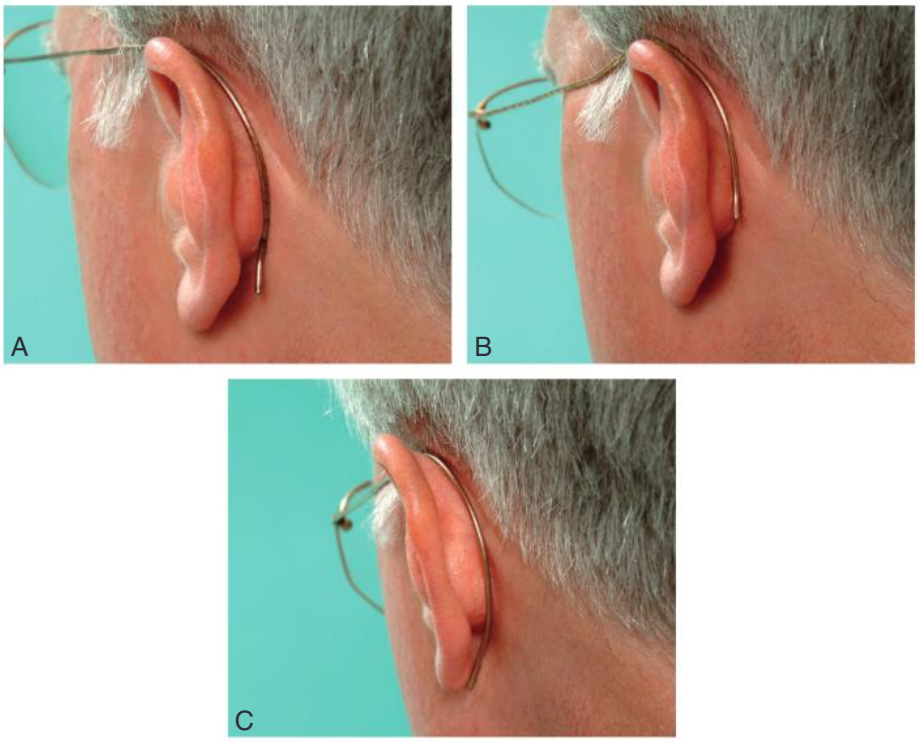


Figure 9.28 In judging correct cable temple length, observe where the temple ends as it wraps around the ear. **A,** The correct length cable temple should stop just short of the lower lobe of the ear. **B,** Cable temples that are too short do not have the length to grip the lower portion of the ear where it is most necessary. **C,** Cable temples that are too long have a tendency to dig into the lower ear lobe. If no shorter temples are available, it is possible to clip off the end of the temple with cutting pliers and solder the new end. A small ball of solder at the tip will make a smooth surface and keep the coiled cable from unraveling.

to left side of the face so that the left temple comes off the ear easily. Do the opposite with the left hand only.

3. For frames with cable and comfort cable temples, grasp the right endpiece with the right hand. With the left hand grasp the tip end of the left cable temple (Figure 9.29). Pull the left temple off the ear and swing the glasses to the right so that the right cable temple comes off the ear easily.

Figure 9.29 Taking frames with cable temples off the face is done by grasping the tip of one temple and pulling it back and around the ear while holding the other temple near the frame front.

4. To lay the glasses down on a table or dresser with the temples open, place the glasses on the surface upside down. When the temples are closed, place the glasses with the folded temples down. Never place the glasses on a surface with the lenses facing down.
5. Do not leave the glasses on the dashboard of a car or where they will be exposed to heat.
6. When not being worn, glasses do best in a case. This is especially true when being carried in a purse or pocket.
7. Rinse the lenses before wiping them with a cloth. Microfiber cleaning cloths are typically used dry. However, it is still best to rinse the lenses with water ahead of time to clear any fine grit that could potentially scratch the lens surfaces when being rubbed with the cloth. (Microfiber cloths need to be periodically washed as well!) Remember that the frames need cleaning, too. Washing frames and lenses in a mild detergent, as when doing dishes, is appropriate.

   For more on cleaning frames and lenses, see the section on *Cleaning Frames and Lenses* in Chapter 7, including Tables 7.3 and 7.4.

FITTING ADJUSTABLE NOSE PADS

Adjustable nose pads give tremendous versatility when fitting and adjusting frames. Unfortunately, many are unfamiliar with the basics of how to adjust nose pads correctly and are afraid of making changes. This section presents step-by-step methods for doing just what is needed to correctly position the frame.

Where adjustable pads and pad arms are available, the frame can be altered in height by widening or narrowing the distance between the

pads. It should be remembered, however, that increasing or decreasing the distance between pads will not only lower or raise the frame on the face but also allows the frame to fit closer to or farther from the eyes.

There are primarily two types of adjustable pad arms. The older type is shaped like a question mark; the more common like an upside down U or a gooseneck.

PROPER PAD ANGLES FOR ADJUSTABLE PADS

With any pad adjustment that moves a pad arm, it can be expected that afterward, the face of the pad may no longer sit flat on the nose. The pads must then be realigned to their proper positions so that frontal, splay, and vertical angles are once again correct. These angles are explained in Chapter 8.

Remember to adjust the pantoscopic angle (tilt of the frame front) *first* before adjusting the three pad angles. The tilt of the frame front changes how the pads sit on the surface of the nose. Adjusting the pantoscopic angle after aligning the pads means that the pads will have to be aligned all over again.

Achieving the Proper Pad Angles for Adjustable Bridges

The adjustment of rocking pads is most easily performed using pad-adjusting pliers. (See Figure 8.57 in Chapter 8.) These special pad pliers come in a variety of configurations. They should be chosen for the pad attachment type on the frame. Attachment styles change with the times, so the type of pad-adjusting pliers that have been in the office for years may no longer be appropriate for the frames being currently used.

Pad-adjusting pliers, when chosen properly, have one jaw that holds the base of the pad securely without crushing the pad socket or attachment and another jaw that cradles the face of the pad. The pad can readily be adjusted for splay, vertical, and frontal angles using these pliers. Snipe-nosed or other flat-jawed pliers can also be used on the pad support arm. If used on the face of some pads, they may indent or mar the pad face surface.

For pads to be adjusted to rest correctly on the surface of the nose, they should fulfill the following criteria:

1. The pads should rest halfway between the crest of the nose and the inner corner of the eye (Figure 9.30).
2. The long diameter of the pads should be perpendicular to the floor when the head is erect (as also seen in Figure 9.30).
3. The full surface of the pads should rest uniformly on the nose. If either the lower, upper, inner, or outer edge of the pad presses unevenly on the surface of the nose, the nose will show imprint or cutting marks after wear, or may become too sensitive for continued wear.

To correct these problems, the pad face should be readjusted as listed below:

1. If the lower edge cuts in (as in Figure 9.31), change the frontal angle by moving the bottom of the pads apart.
2. If the top edge cuts in (as in Figure 9.32), change the frontal angle by moving the lower part of the pads closer to each other.
3. If the front edge cuts in (as in Figure 9.33), decrease the splay of the pads.
4. If the back edge cuts in (as in Figure 9.34), increase the splay of the pads.
5. If the cutting edges seem oblique, the pad is not vertical. Alter the vertical angle, and readjust to correct for one or more of the errors listed above.
6. If the upper part of the pad surface seems to be parallel to the nose but the lower part is not, or vice versa, change to a flexible, silicone pad that will conform more readily to changes in nasal angles.

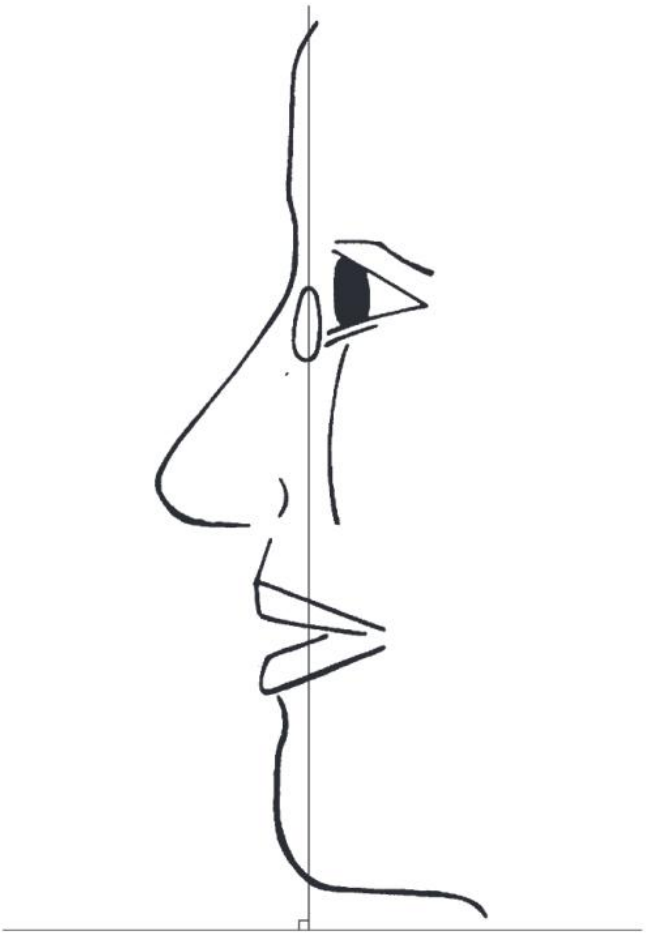


Figure 9.30 The proper resting position for adjustable pads is halfway between the crest of the nose and the inner corner of the eye. The long axis of the pad should be perpendicular to the floor.

(Note: If the wearer does not like the feel of silicone pads, it is possible to heat the stiff plastic pads and bend them to match the curve of the nose surface. This condition may occur where the very upper part of the bridge of the nose is thin and straight and the nose suddenly flares and splays widely within the dimension of the pad.)

When Pad Angles Are Correct but Still Slide Down or Hurt

Sometimes even when the pad angles are correct and the frame is adjusted properly, the glasses still have a tendency to slide. This may occur when the frontal angle of the nose is almost straight up and down. When this happens, replace the nose pads with replacement pads made from silicone material. This assumes, of course, that the pads are not already of the flexible silicone variety.

Another alternative is to replace the existing pad with a larger pad. This is especially helpful when the pad is causing an irritation to the skin as often happens in older wearers as the skin loses its elasticity.

A third possibility is to replace both pads with a *strap bridge*. A strap bridge is like two adjustable nose pads that are joined together in straplike fashion. The strap bridge increases the surface area upon which the frame weight rests and is shown in Figure 10.51.

Strap bridges are adjusted like regular nose pads because each side of this flexible bridge has its own pad arm. To get full benefit from the replacement bridge, care should be taken to assure that the upper strap area rests on the crest of the nose and assists in bearing the weight of the frame.

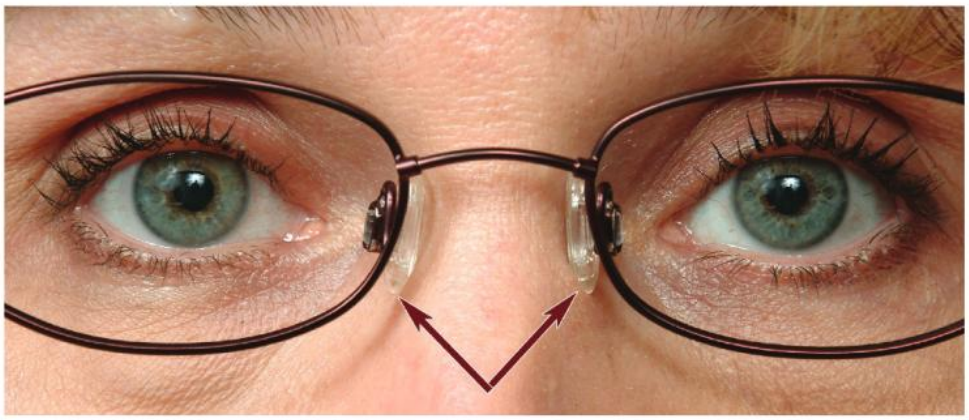


Figure 9.31 Here, the lower edges of the pads cut into the nose surface. If the skin on the nose is flaccid, the error is not as visible. It can be detected if the glasses have been worn for a period of time by U-shaped red marks on the nose. The frontal angle is wrong and must be corrected.

Figure 9.32 If the upper edges of the pads indent, the frontal angle must be more vertically oriented.

Figure 9.33 This illustration, viewed from the top in cross-section, shows a pad splay angle too great for the nose. The splay angle of the pads must be decreased.

After saying all of this about sliding, hurting pads, the underlying issue could well be the weight of the glasses. Therefore, when selecting frames and lenses, the lenses should be lighter in weight—perhaps of a high-index material. The frames should be selected to avoid larger eye-sizes and effective diameters. In short, choose a frame appropriate for a high-powered prescription.

Adjusting Pad Angles for Rimless or Semirimless Mountings

When adjusting the pads of a rimless mounting, certain precautions should be taken to prevent damaging the lens at the point of attachment. A good option is to use rimless adjusting pliers (as shown in Figure 8.65) to hold the lens at its nasal point of attachment, while adjusting the pad angle with pad- adjusting pliers (Figure 9.35, *A*). Some frames may not make this an absolute necessity because the pad arm is attached to the top of the bridge. In this case, or when rimless adjusting pliers are not available, it is possible to hold the bridge of the frame while adjusting the pad as in Figure 9.35, *B*. Another option is to hold the lens with the thumb and forefinger at the point of attachment while adjusting the pads (Figure 9.36). Which option may be best will depend upon the construction of the frame.

FRAME HEIGHT AND VERTEX DISTANCE

Achieving the Correct Frame Height

Once the pantoscopic angle has been established satisfactorily, the next step is to place the frame at the correct height. Most judgments for single-vision lenses are based on the position of the frame relative to the brows and orbits (Figure 9.37). It is not difficult to change the vertical height for frames with adjustable pad bridges. For frames with adjustable pad bridges, frame heights can be changed by widening or narrowing the distance between pads.

The primary reasons for widening or narrowing the bridge area are shown in Box 9.1.

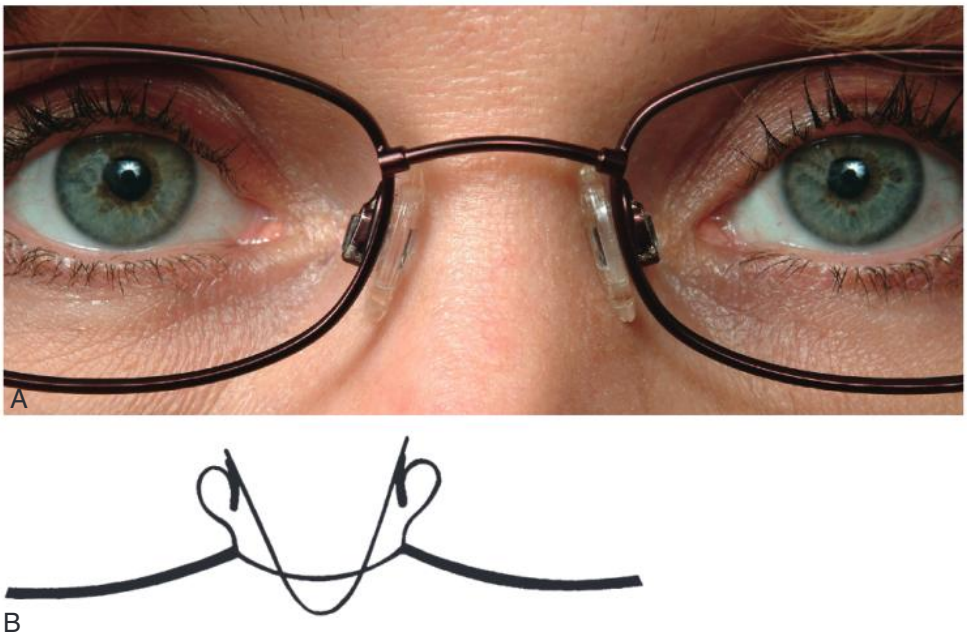


Figure 9.34 In **A,** the splay angle of the pads needs to be increased. The back edges of the pads will cut into the flesh of the nose unless corrected. Notice how the metal support within the pad is visible from the front. This observation is helpful in determining this type of adjustment error. In **B**, the same situation is shown schematically in cross-section.

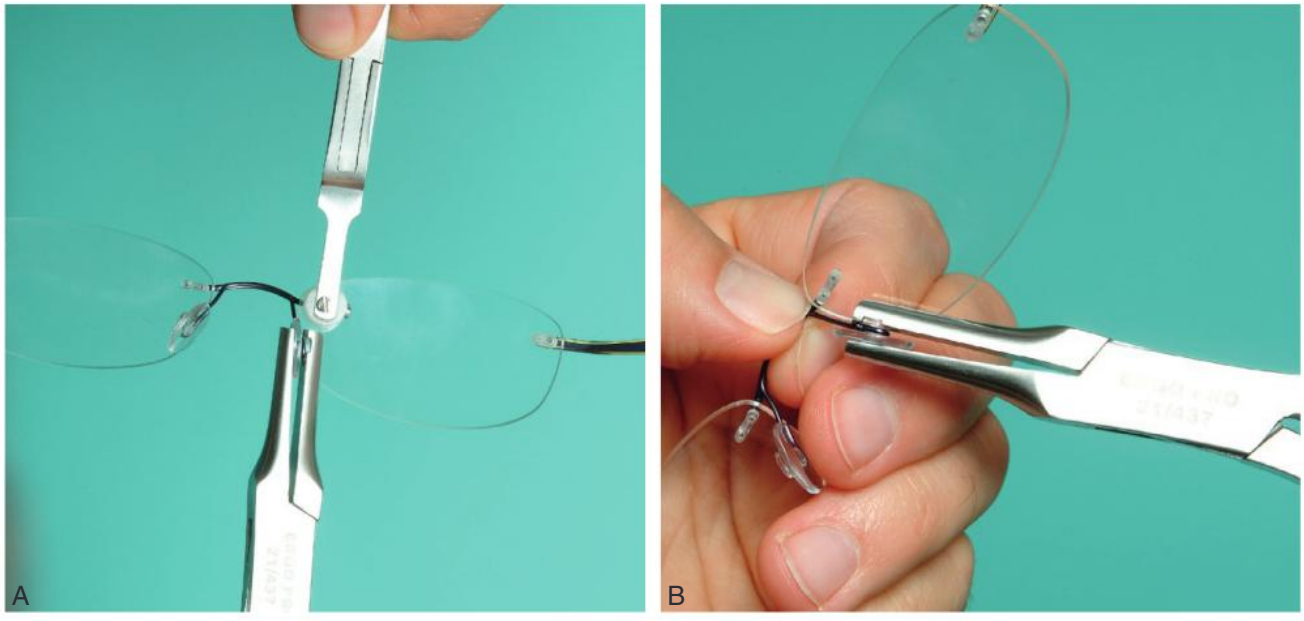


Figure 9.35 A. Depending upon frame construction, holding the lens with rimless adjusting pliers while adjusting the pad angle may prevent damage to the lens at its point of attachment. For this particular frame, this is actually not the best option since the pad arm is attached directly to the bridge. A better option is shown in **B. B,** If the frame is constructed with the pad arm attached more to the bridge, holding the bridge while adjusting the pad may be sufficient.

Proper Vertex Distance

On occasion, it becomes necessary to change the distance between the frame and the face. This is referred to as changing the *vertex distance* or, more specifically, the distance from the front surface of the eye to the back of the spectacle lens. This type of change might be required if, for example, the top of the frame was resting against the brows or the bottom eyewire was touching the cheeks and neither error could be corrected by a change of pantoscopic angle. Increasing the vertex distance is also often necessary to keep the eyelashes from brushing against the back surface of the lens.

Decreasing the vertex distance, or bringing the frame closer to the face, may be required for purely cosmetic reasons. Decreasing the vertex distance will also provide a wider field of corrected vision. For example, the closer a person stands to a window, the farther to the left

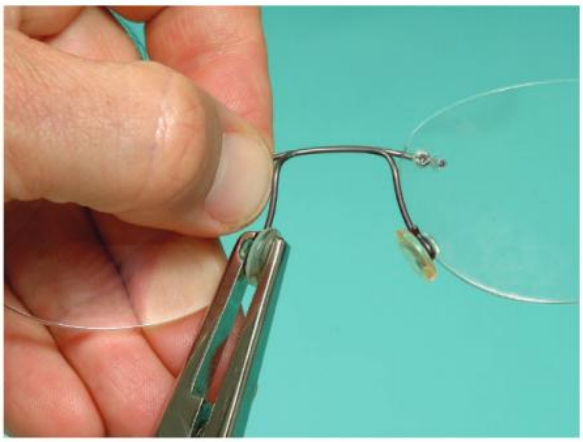


Figure 9.36 If there are no rimless adjusting pliers available, a precaution while adjusting pad angles is to hold the lens tightly between thumb and forefinger at the point of attachment. This helps remove some of the stress from the lens during adjustment. The most appropriate procedure from the three shown in this and Figures 9.34 and 9.35 will depend upon frame construction. In this figure sequence (Figure 9.35 and this figure), the most appropriate procedure for this particular frame is shown in Figure 9.35, *B*.

BOX 9.1 Reasons for Widening or Narrowing the Distance Between Nose Pads

Widening the distance between nose pads would be appropriate in cases in which:

1. The frame is too high on the face.
2. The bifocal or trifocal segments are too high.
3. The progressive addition fitting cross heights are too high.
4. The bridge is too small for the nose.
5. The lenses are too far from the eyes.

Narrowing the distance between nose pads would be appropriate in cases in which:

1. The frame sits too low on the face.
2. The bifocal or trifocal segments are too low.
3. The progressive addition fitting cross heights are too low.
4. The bridge is too large for the nose.
5. The lashes rub the back surface of the lenses.

and right he or she can see. By the same principle, the closer the frame is to the face, the more viewing area is visible through the lens. The overall field of view increases (Figure 9.38, *A*). Increasing the pantoscopic tilt also increases the lower field of view (see Figure 9.38, *B*).

For the bifocal wearer, moving the frame closer to the face increases the field of view above the bifocal without the necessity of lowering the segment. This same effect can be produced by increasing the pantoscopic tilt. (See Chapter 5 for specifics.)

When very strong lenses are involved, precise vertex placement becomes quite important. In some instances, small alterations in the vertex distance of the finished spectacles may affect vision significantly.

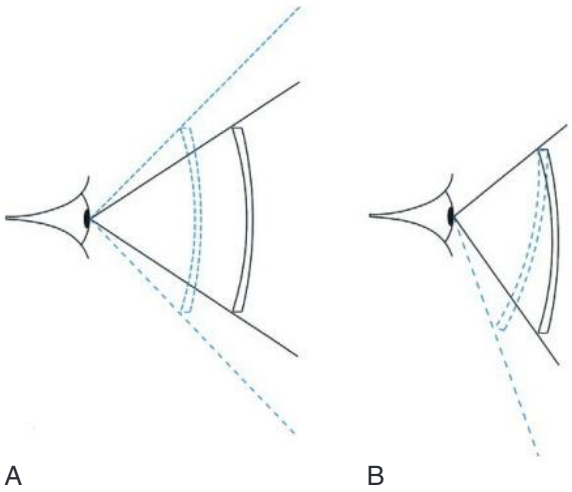


Figure 9.38 When a lens is moved closer to the eye, the field of view increases as shown in **A.** Pantoscopic tilt also increases the field of view in the lower lens area as shown in **B.** Increasing the pantoscopic angle is particularly helpful for increasing the near viewing area through bifocals, trifocals, and progressive add lenses.

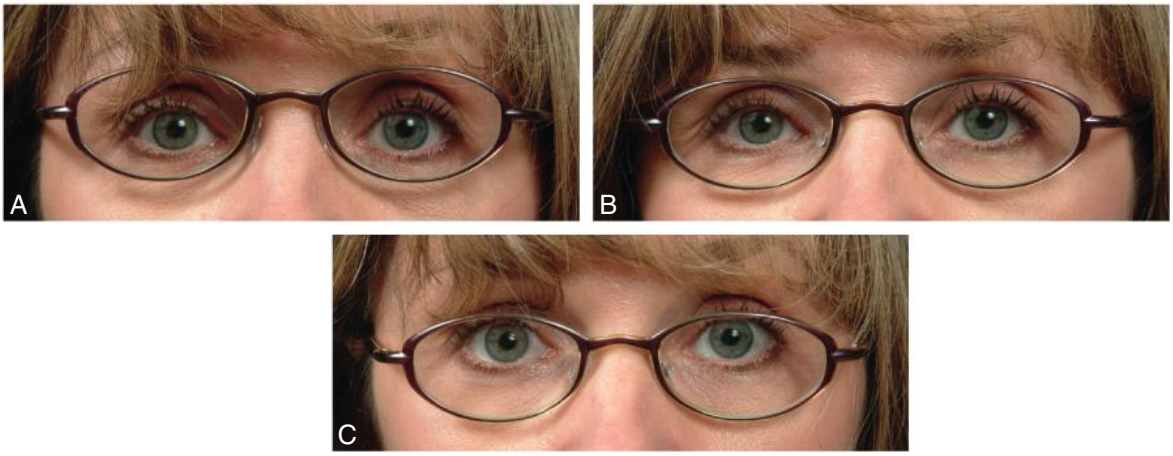


Figure 9.37 For conventional eyewear, frame height is based on a combination of eye, eyebrow, and orbit positions. In **A,** the frame rides too high. In **B,** the height is correct for the frame shown. In **C,** the frame is too low. Some large frames are even designed with upper rims above the brows. As fashion continues to circle around, this can be expected to come and go. In any case, such frames should still be fitted at a height that conforms to standards discussed in Chapter 4, *Frame Selection*.

ADJUSTING NOSE PADS WITH INVERTED U-SHAPED PAD ARMS

Changing the Distance Between Pads for "Inverted U-Shaped" Pad Arms

The inverted U-shaped pad arm varies in how much it may be adjusted, depending upon how high the U arches. If there is not much length to the pad arm, the extent that it may be adjusted is limited. But if there is "extra" length to work with, the dispenser will have more latitude in making frame height and vertex distance changes (Figure 9.39).

Most pad adjustments may be done in two movements. The first move makes the change; the second move completes the change and restores the proper pad angle. (This assumes we get it right the first time!)

Widening the Distance Between Pads

When the distance between pads is too small and does not fit the nose, we need to widen the distance between pads. To *widen* the distance between pads, grasp the pad with pad-adjusting pliers (Figure 9.40, *A*).

1. First, tilt the top of the pliers outward (temporally) while simultaneously exerting some outward (temporalward) pressure. *The pivot point is at the point of attachment of the pad arm.* This will cause the top of the U to tilt away from the nose, bending the pad arm at its base (see Figure 9.40, *B*). This moves the pad temporally and changes the frontal angle.
2. Next, without removing the pliers from the pad, tilt the bottom of the pliers outward. *Now the pivot point should be the top of the pad arm's inverted U.* This will cause the U to bend at the top, with the center of the pad moving temporally (see Figure 9.40, *C*). Again, during this movement, there should be some simultaneous outward pressure applied. While the first bend (Step 1) will change the frontal angle of the pad, the second bend (Step 2) will restore it. (If there is not at least some simultaneous outward pressure applied during both movements, the pad may end up at nearly the same location as it was when we started!)

   Figure 9.40, *D,* shows the left pad "widened" and the right pad still in the original position.

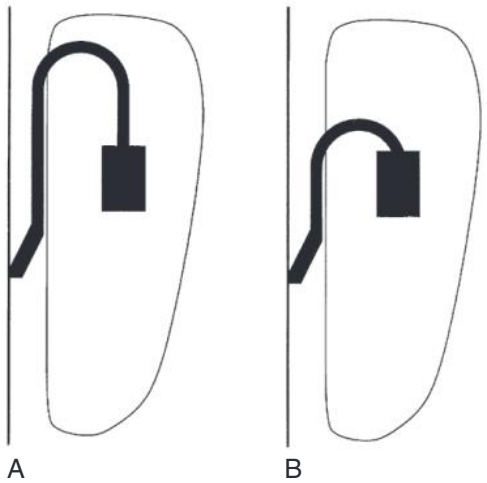


Figure 9.39 The U-shaped pad arm **(A)** has sufficient length to allow frame height and vertex distance changes. The pad arm **(B)** will allow only minimal changes in height and vertex distance, although it may allow some change in the distance between pads.

Narrowing the Distance Between Pads

To *decrease* the distance between pads, the same type of two-step sequence occurs as was described for widening the distance between pads except that the bends are in a nasal or inward direction instead of outward.

1. For the first bend, the top of the pliers are tilted inward (nasally). *Again the pivot point is at the point of attachment of the pad arm.* Remember to simultaneously apply some inward (nasalward) pressure.
2. For the second bend, follow up by tilting the bottom of the pliers inward, completing the bend, and restoring the frontal angle. *The pivot point is the top of the pad arm's inverted U.* Again, remember to also apply some inward (nasalward) pressure.

Moving the Frame Left or Right

(This adjustment uses a combination of the two adjustments that have just been explained: narrowing the distance between pads and widening the distance between pads.)

A frame may sit too far left or right on the face as shown in Figure 9.41. There are two possible causes for this problem.

1. The nose pads on the frame are positioned asymmetrically.
2. The wearer's nose is asymmetrical.

When the Nose Pads Are Asymmetrical

The first possible cause for a frame sitting too far to the left or right on the wearer's face is that the nose pads on the frame are asymmetrical. If the fault is with the frame, the pads themselves are moved slightly too far to one side or the other, even though they may sit flat on the nose and be comfortable (Figure 9.42). The problem is corrected by moving one pad nasally and the other pad temporally. The procedure for moving one pad nasally is the same as was described for decreasing the distance between pads. The procedure for moving the other pad temporally is the same as was described for increasing the distance between pads.

Adjust both sets of pad arms so that they are mirror images of each other. The left and right pad arms are made to be symmetrical.

When the Wearer's Nose Is Asymmetrical

The second possible cause for a frame being too far left or right is that the person's nose is asymmetrical. This is quite a common occurrence because many people have had a broken nose at one time or another. If the break was far enough back on the nose, it will cause the frame to sit off center, even though the pad arms and pads are symmetrical.

To check for such an error, look at the frame from the straight-ahead position. If the frame is toward the *right side of the wearer's face*, bend the pad arms at their bases *in the direction of the wearer's right lens* and then realign the pad angles. If the frame is toward the *wearer's left*, bend the pad arms toward the *left lens*. The direction of the bend may be remembered logically by keeping in mind that moving the pad arms one way pushes the frame in the opposite direction. It may be remembered by rote by thinking "Frame to the right, move pads to the right. RIGHT-RIGHT," and "Frame to the left, move pads to the left. LEFT-LEFT."

Recapping for Remembering

Up to this point, we have simple consistency for memorization purposes between observed error and proper correction of that error.

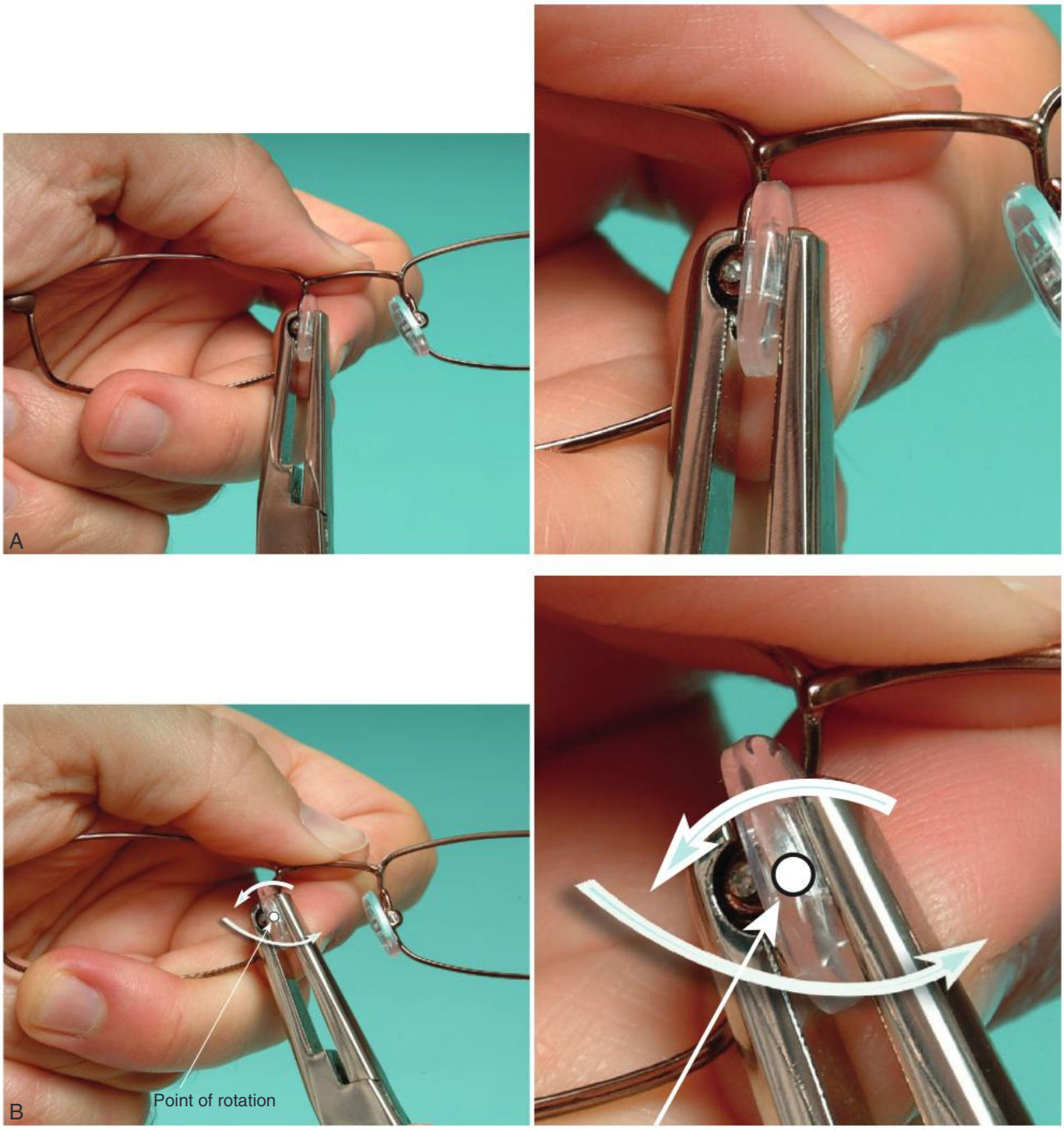


Figure 9.40 To increase the distance between pads for frames having U-shaped pad arms, the sequence is:
- Grasp the pad with pad-adjusting pliers **(A).**
- Tilt the top of the pliers outward temporally **(B).** The point of rotation is at the point of attachment of the pad arm. This will decrease the frontal angle.

(Continued)

The consistent relationship between the direction of the error and the direction of correction for that error helps simplify any required memorization.

For equality of vertex distance:

One lens in, bend same temple in: IN-IN.
One lens out, bend same temple out: OUT-OUT.

For straightness of the frame on the face:

One side up, bend same temple up: UP-UP.
One side down, bend same temple down: DOWN-DOWN.

For symmetry of the frame on the face:

Frame to the right, move pads to the right: RIGHT-RIGHT.
Frame to the left, move pads to the left: LEFT-LEFT.

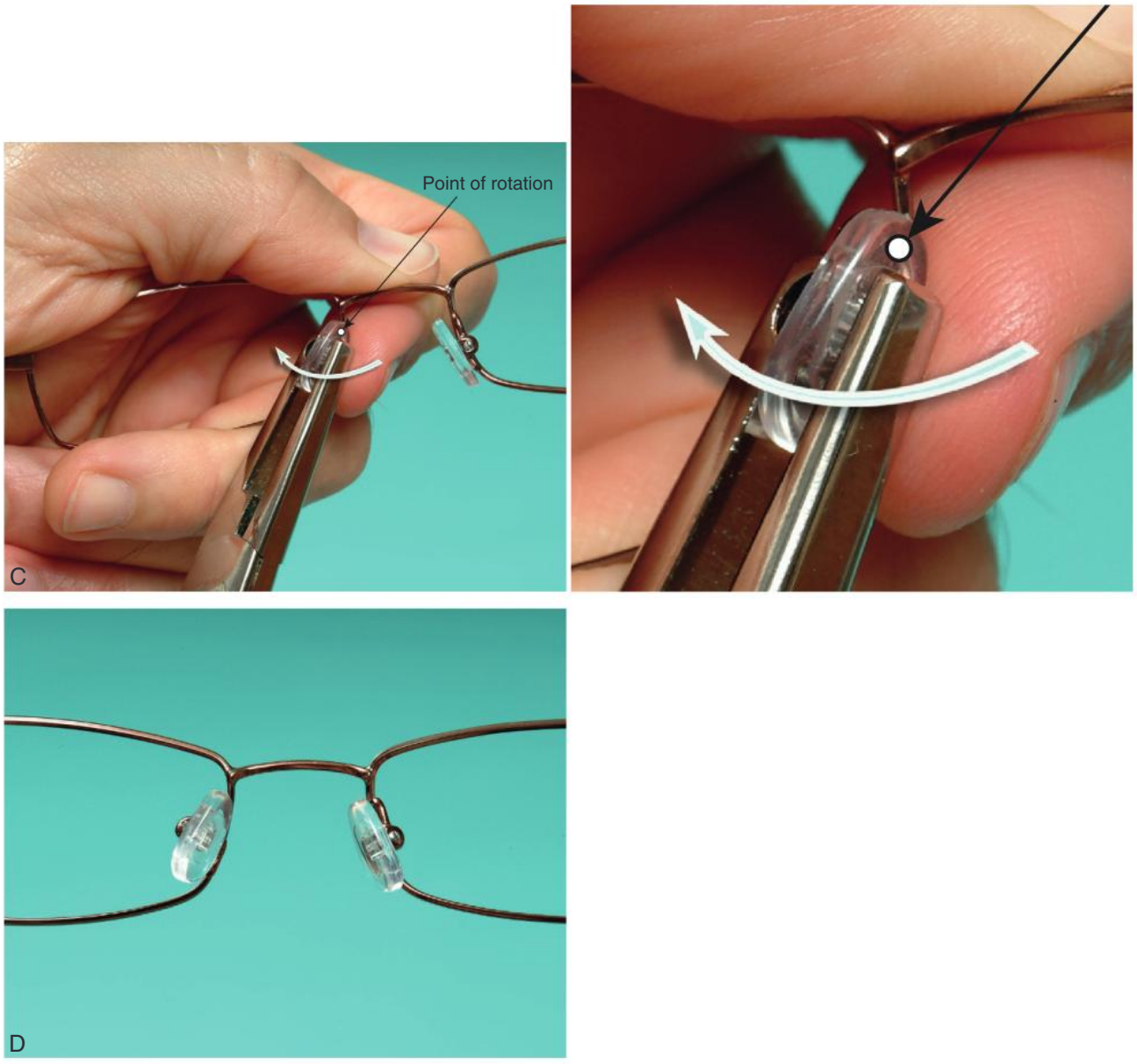


Figure 9.40, cont'd

- Next, turn the bottom of the pliers temporalward with the pivot point being the top of the pad arm's inverted U **(C).** This will move the face of the pad temporally and will allow the frontal angle of the pad to be returned to the necessary angle.
- The pad on the left pad has been "widened" (moved outward) **(D).**

Changing Frame Height but Not Vertex Distance

Changing the Height of Pads for Inverted U-Style Pad Arms

Most of the time a frame will be moved higher or lower on the face by narrowing or widening the distance between pads. (This procedure was described earlier.) However, narrowing or widening the distance between pads will also cause the frame to move farther from or closer to the eyes. The distance from the lenses to the eyes is called the vertex distance. To keep the vertex distance the same, the distance between the pads must remain the same. This means that in order to change the height of the frame, the location of the pads relative to the frame front must move up or down.

Moving the frame higher or lower on the face without changing the distance between pads is accomplished for inverted U-style pad arms by changing the location of the bend or loop at the top of the U in the pad arm.

Lowering the Frame

To lower the frame on the face without changing the vertex distance, the location of the bend in the pad arm is changed. This is shown in Figure 9.43. The adjustment itself may be made with two moves. These are:

1. Grasp the pad with pad-adjusting pliers as seen in Figure 9.44, *A*. *While exerting an upward pull on the pad*, simultaneously bend the

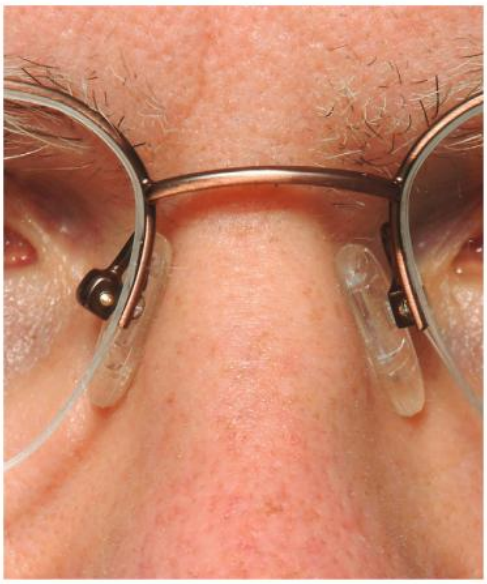


Figure 9.41 An example of a frame that sits too far to the wearer's left. Note that when the pads are shifted to the wearer's right, the frame shifts to the wearer's left.

Figure 9.42 In this photo, the pad angles are basically symmetrical, but the pads themselves are moved too far to one side. This defect as shown from above will cause the frame to sit too far to the wearer's left, as was shown in the previous figure.

pad arm until the posterior part of the U is angled outward from the frame front as shown in Figure 9.44, *B*. Notice that there are two arrows of force in the drawing. Both of these forces are taking place at the same time.

2. Bend the pad arm back down into place, *while simultaneously pushing upward with the pliers* (see Figure 9.44, *C*). Again, notice that there are two arrows of force in the drawing. As before, both are taking place at the same time.

It may be necessary to repeat these two steps if the pad has not moved up enough. Without an upward pull during Step 1 and an upward push in Step 2, there will not be any appreciable change in pad height.

The finished pad is shown in Figure 9.44, *D*. The other pad is then adjusted to match.

Raising the Frame

To raise the frame on the face without changing the vertex distance, the location of the bend in the pad arm is again moved—but this time in the opposite direction. This is the reverse of that described for lowering the frame. It is a bit harder to master as is lowering the frame, yet becomes easier with practice. Therefore, even though it is theoretically feasible to make this adjustment with two moves, the process may need to be repeated.

1. Grasp the pad with pad-adjusting pliers. *While exerting a downward pull on the pad,* bend the pad arm until the posterior part of the U is angled outward from the frame front.
2. Still exerting a downward pull on the pad, bring the pad arm back to its correct angle. (Care should be taken so as not to inadvertently pull the pad away from the frame front.)

To an outward observer, the movements for lowering and raising the frame look the same. The only difference is whether the force is in an upward or a downward direction. For raising the frame, look at Figure 9.44 again. This time substitute downward vertical arrows in Figure 9.44, *B* and *C*. for the upward vertical arrows shown. Pulling the nose pads downward raises the frame on the face.

Both pads should still have the same horizontal distance between them, will rest on the same position of the nose, and because they have been moved lower, will cause the frame to sit higher on the face. This is illustrated in Figure 9.45.

Changing Vertex Distance but Not Height

It is possible to change the vertex distance by narrowing or widening the distance between pads. A secondary effect is an increase or decrease in the overall height of the frame. When frame height is correct to begin with, nose pads should be adjusted a different way.

Increasing the Vertex Distance

The sequence for increasing the vertex distance is done with two moves. This is shown in Figure 9.46. Here is how it is done:

1. The pad is grasped with pad-adjusting pliers, and the top of the pad is rotated away from the frame front (Figure 9.46, *A*). The point of rotation is at the point of attachment of the pad arm. The pad arm bends at the point of attachment. This changes the vertical angle of the nose pad.
2. The vertical angle can be immediately corrected without repositioning the pliers. The angle is changed by moving the lower part of the pad away from the frame front. The point of rotation is the top of the inverted U. The rotation of the pliers is indicated by the arrow shown in Figure 9.46, *B*. This corrects the vertical angle (see Figure 9.46, *C*).

The end result is seen in Figure 9.46, *D*.

Decreasing the Vertex Distance

To decrease the vertex distance, the pads must be positioned closer to the frame front. As with most pad adjustments, this adjustment may be done with just two moves. The pad is grasped with pad-adjusting pliers as in Figure 9.47, *A*. Here is the sequence:

1. Bend the bottom of the pad away from the frame front while pressing the top of the pad toward the frame front as shown in Figure 9.47, *B*.
2. Next, swing the bottom of the pad toward the frame front without allowing the top of the pad to move (Figure 9.48, *C*). If the pliers do not have enough room to swing the lower part of the pad inward, turn them upside down and grasp the pad from above.

The completed work is shown from the top in Figure 9.47, *D* where right and left pad distances are compared. The pad should still have the same alignment angles as before (frontal, splay, and vertical). The pad is

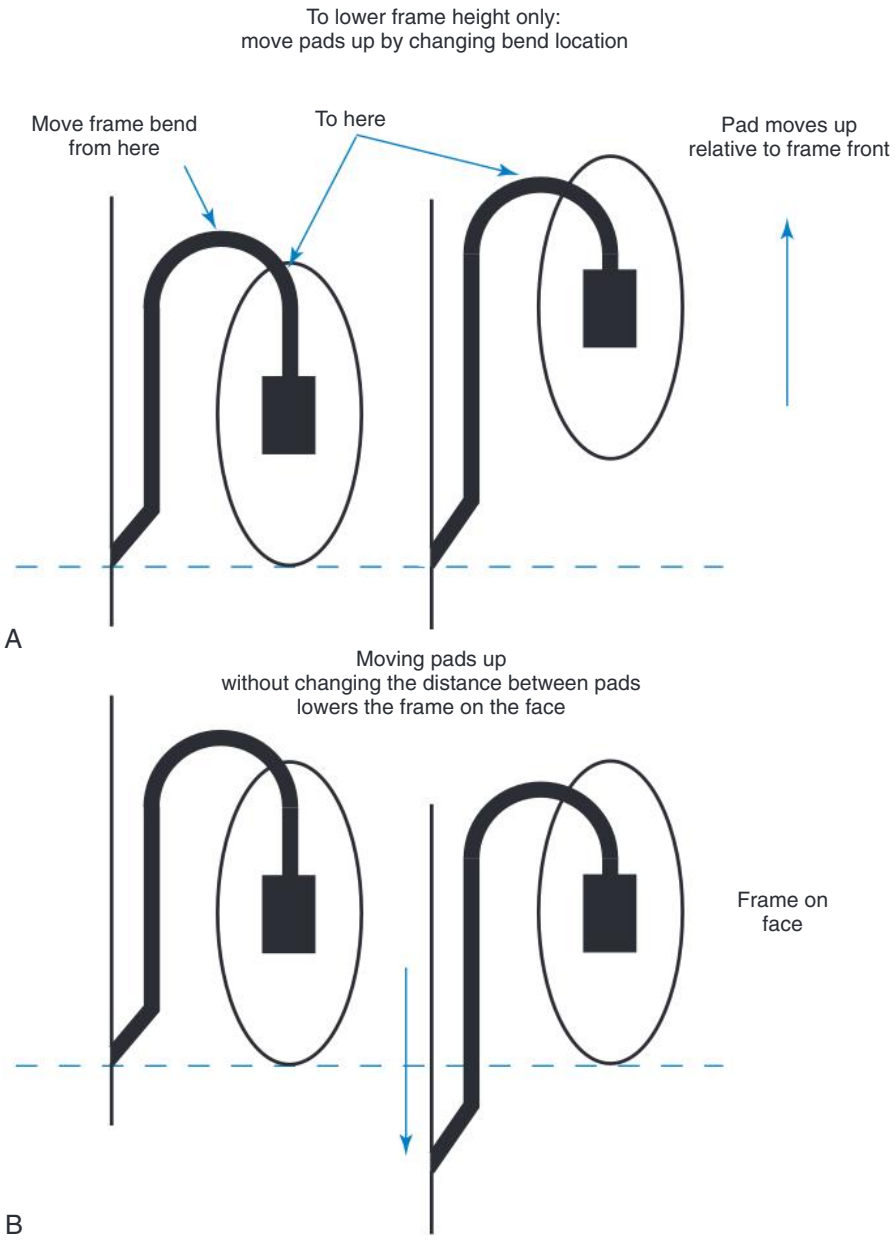


Figure 9.43 To lower the frame on the face without changing the vertex distance, the pads are moved up, but the right and left pads are still the same distance apart. This means that the pads will rest on the nose as they did before. However, the frame, being lower relative to the pads, will also be lower on the wearer's face. **A,** If the bend in the pad arm is moved closer to the pad, the pad moves up. **B,** Because the pad will sit on the nose where it did before, the frame will be lower.

just farther forward (closer to the frame front). When both pads are completed, the frame will rest closer to the eyes.

ADJUSTING NOSE PADS WITH QUESTION MARK–STYLE PAD ARMS

Nose pads supported by pad arms that look like a question mark when viewed from the top were the predominant type of pad arm. Now, they are a minority. However, they do continue to appear, sometimes as part of a "hybrid" combination of the inverted U and question mark. These types of pad arms are very versatile and in some ways allow easier changes in frame height and vertex distance.

Changing the Distance Between Pads for Question Mark–Style Pad Arms

Regardless of pad or pad arm style, widening the distance between pads will lower the frame and allow it to sit closer to the face. Narrowing the distance between pads will raise the frame and cause it to sit farther from the face.

Widening the Distance Between Pads: Question Mark Style

When working with question mark–style pads, some prefer to use pad-adjusting pliers on the face of the pad; others would rather use thin-nosed pliers and grasp the pad arm directly.

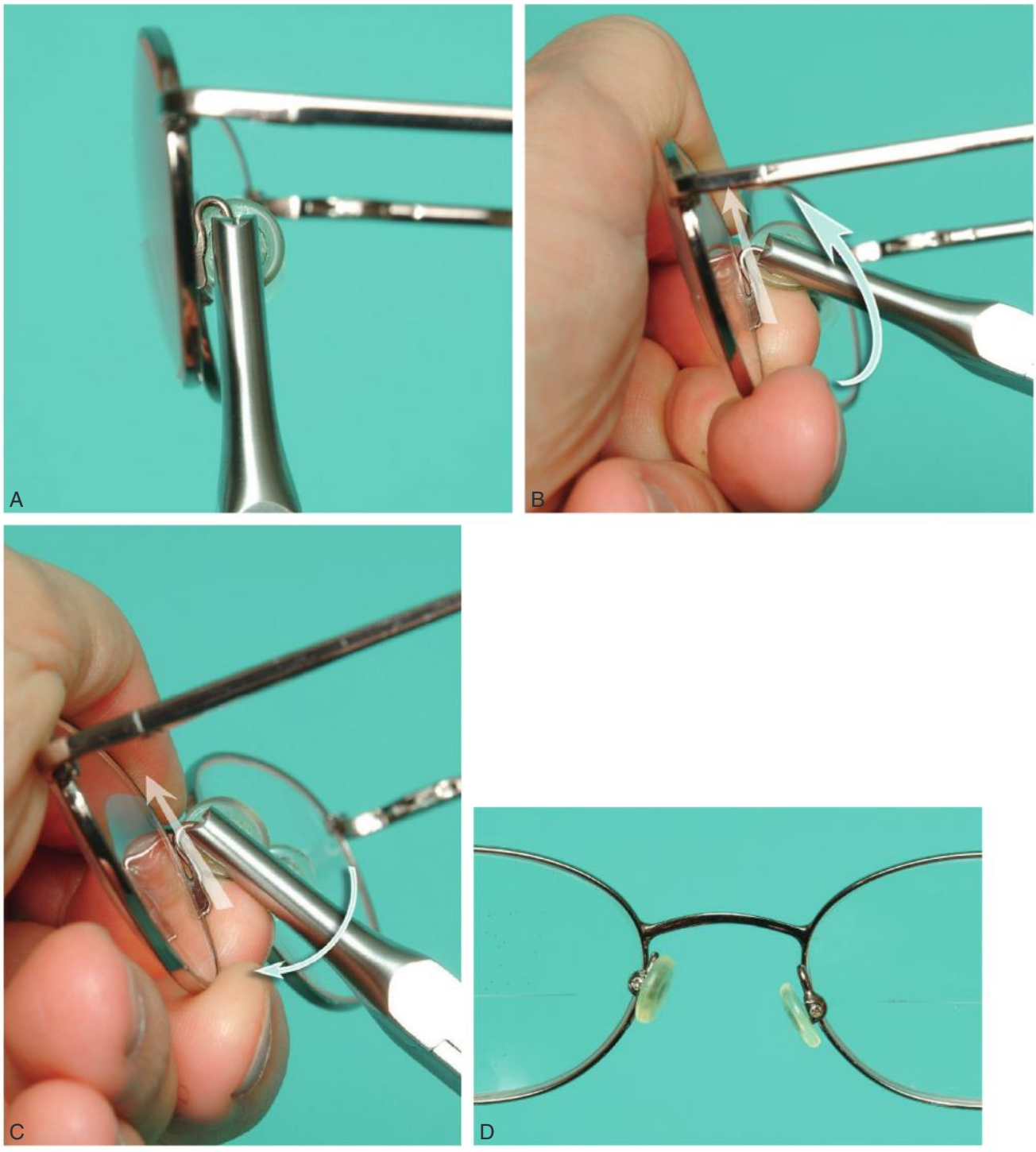


Figure 9.44 To raise the pad (lowering the frame on the face), grasp the pad with the pad-adjusting pliers **(A).** The pad may be raised in two moves. First, angle the pad arm outward while pulling up on the pad **(B).** Second, the pad is returned to its former location. While reangling the pad back downward, simultaneously, push the pad upward as shown in **(C).** The upward pull **(B)** and upward push **(C)** cause the location of the bend in the U to change its location on the pad arm. (The bend is now further from the point of attachment to the frame and closer to the pad itself.) This raises the vertical position of the pad relative to the frame front. **D,** This shows the difference in pad height produced by this adjustment. (By changing the direction of the *vertical arrow* in parts **B** and **C** from upward to downward, this same photo sequence then shows the procedure for raising the frame on the face.)

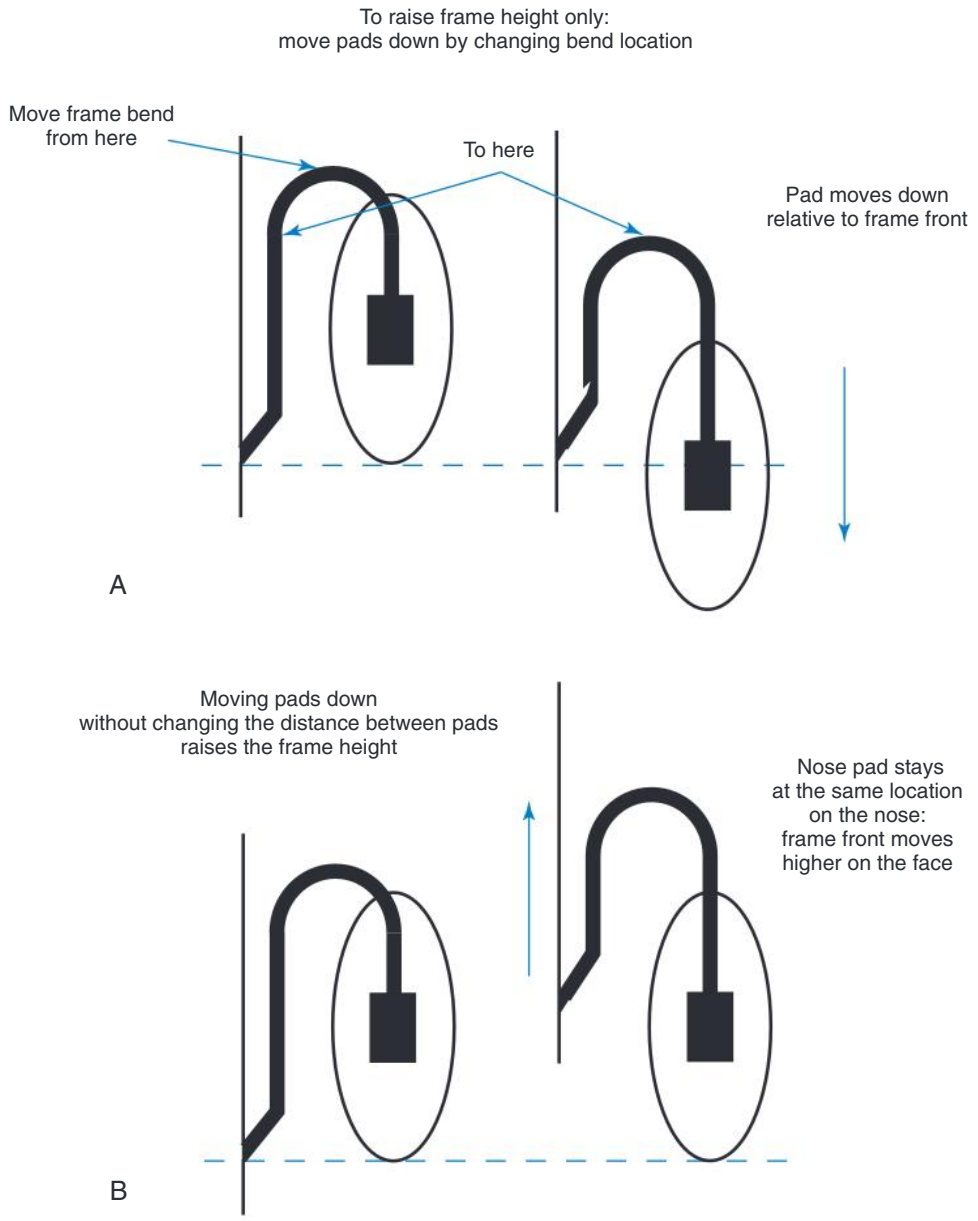


Figure 9.45 To raise the frame on the face without changing the vertex distance, the pads are moved down, but both right and left pads are still the same distance apart. This means they will rest on the nose where they did before. But the frame will be higher on the wearer's face. **A.** If the bend in the pad arm is moved closer to the pad arm's point of attachment, the pad moves down. **B.** Because the pad will sit on the nose where it did before, the frame will end up higher.

Square-round pliers are shown in Figure 9.48. When using square-round pliers, the round jaw will be the pivot point of the pliers (Figure 9.49). It is easier to use thin-nosed pliers with question mark–style pads than with inverted U-shaped pad arms because the pad arm is more easily accessible from the top or the bottom.

Widening the distance between pads can be done in two moves with either type of pliers. The first changes the position of the pad arm but messes up the splay angle. The second move corrects the messed-up splay angle.

Using Pad-Adjusting Pliers

Here are the two moves for widening the distance between pads using pad-adjusting pliers:

1. Grasp the pad with pad-adjusting pliers and move the pad arm temporally (outward). The bend takes place at the point of attachment of the pad arm and rotates around that point (Figure 9.50, *A*).
2. Correct the splay angle by rotating the pliers with the point of rotation at the center of the pad-arm curl (see Figure 9.50, *B*). Compare the right and left pads in Figure 9.50, *C*. The pad distance on the left has been widened; the one on the right has not.

Using Square-Round Pliers

Here are the two moves for widening the distance between pads using square-round pliers:

1. Grasp the pad arm near the base with square-round pliers held vertically. Bend the pad arm outward. Remember to place the round

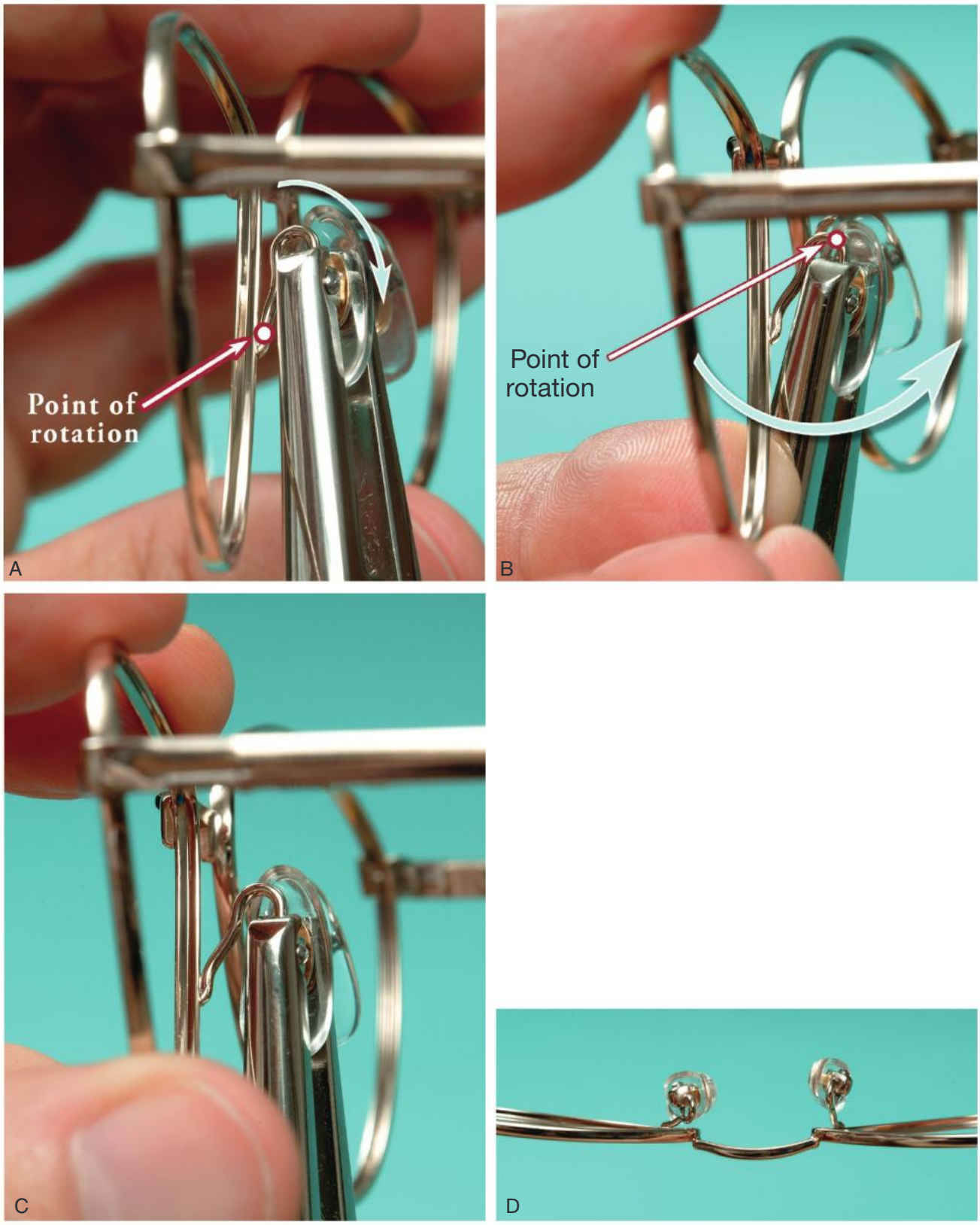


Figure 9.46 Here is the sequence for increasing the vertex distance without changing the height of the frame on the face. **A,** The pad is grasped and the top of the pad moved away from the frame. **B,** The bottom of the pad must now be moved away from the frame to complete the adjustment. **C,** The adjustment is complete. **D,** The pads are shown from the top, and the difference between left and right pads is evident. Now, the pad on the left will be adjusted in an identical manner to match the pad on the right.

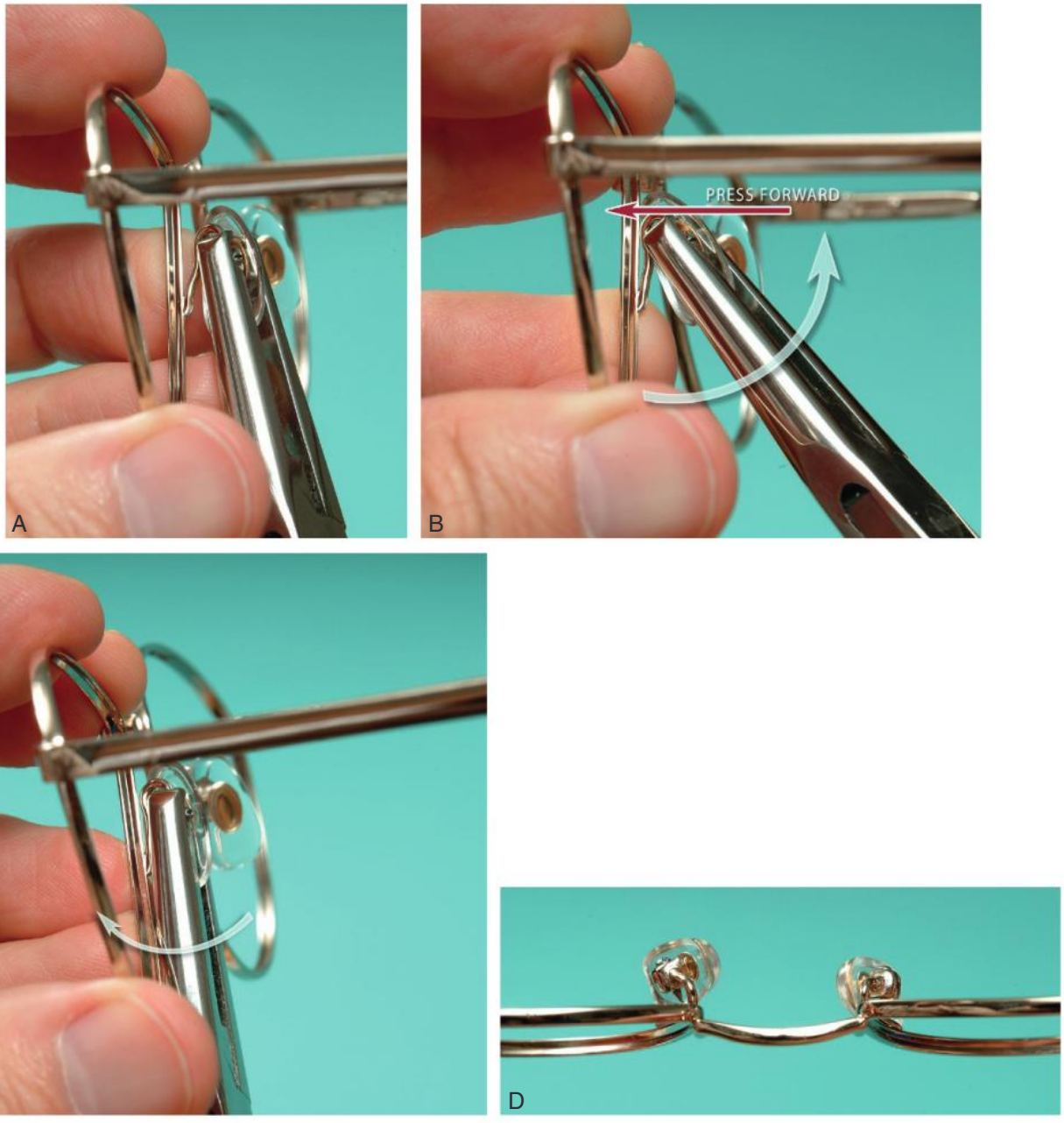


Figure 9.47 The vertex distance may be reduced in just two movements. **A.** The pliers are positioned but have not been moved yet. **B.** The top of the pad is pressed forward. To get the top of the pad solidly forward, the bottom of the pad is rotated back some. **C.** The bottom of the pad is pressed and/or rotated forward. (If there is not enough room for the pliers from below, grasp the pad from above or use thin pliers to grip the pad arm itself.) **D.** The pad on the right is seen to be closer to the frame front than the pad on the left. When the pad on the left is equally adjusted, the frame will sit closer to the face and eyes.

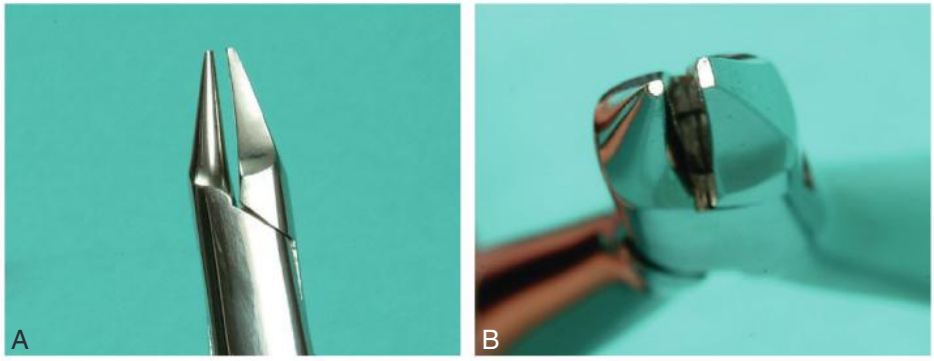


Figure 9.48 The square-round (flat-round) pliers are used for pad arm manipulation. **A,** The left side of the jaw is round, and the right side is squared off and flat on the inner surface. This is seen more easily from above **(B).** The design allows the pad arm to be solidly gripped and smoothly bent.

jaw on the side of the direction the pads are to be moved. Pivot the pliers around the round jaw.

2. Holding the pliers vertically, grasp the pad arm directly in back of the pad and re-angle the splay angle.

Narrowing the Distance Between Pads: Question Mark Style

Narrowing the distance between pads is done the same way as widening the distance between pads was done except that the direction of movement is nasal (inward) instead of temporal (outward). The moves are explained in the steps below and are shown in Figure 9.51.

1. Bend the pad inward.
   a. When using pad-adjusting pliers, grasp the pad, and bend the pad arm inward so the bend takes place at the point of attachment of the pad arm.
   b. When using square-round pliers, grasp the pad arm near the base with square-round pliers held vertically, and bend the pad arm inward. Place the round jaw on the side of the direction the pads are to be moved, and pivot the pliers around the round jaw as was shown in Figure 9.49.
2. Correct the splay angle of the pads.
   a. Use pad-adjusting pliers to correct the splay angle of the pad, or
   b. Use square-round pliers to do the same thing as shown in Figure 9.52.

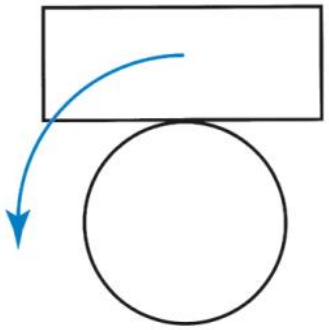


Figure 9.49 To use square-round pliers most effectively, position the pliers so that the round jaw is the pivot point for the bend.

Moving the Frame With Question Mark–Style Pad Arms Left or Right

(Remember that this adjustment uses a combination of the two adjustments that have just been explained: narrowing the distance between pads and widening the distance between pads.)

When the frame sits too far left or right on the face as was shown in Figure 9.41, remember that there are two possible causes for this problem:

1. The nose pads on the frame are positioned asymmetrically.
2. The wearer's nose is asymmetrical.

To correct the problem, bend one pad arm inward (as in narrowing the distance between pads) and the other outward (as in widening the distance between pads). The entire sequence when using square-round pliers is shown in Figure 9.53.

Changing Frame Height but Not Vertex Distance for Question Mark–Style Pad Arms

To change the frame height but not the distance from the frame to the eyes, the distance between the pads must remain the same, but the pads must be either higher or lower. This will move the frame down or up.

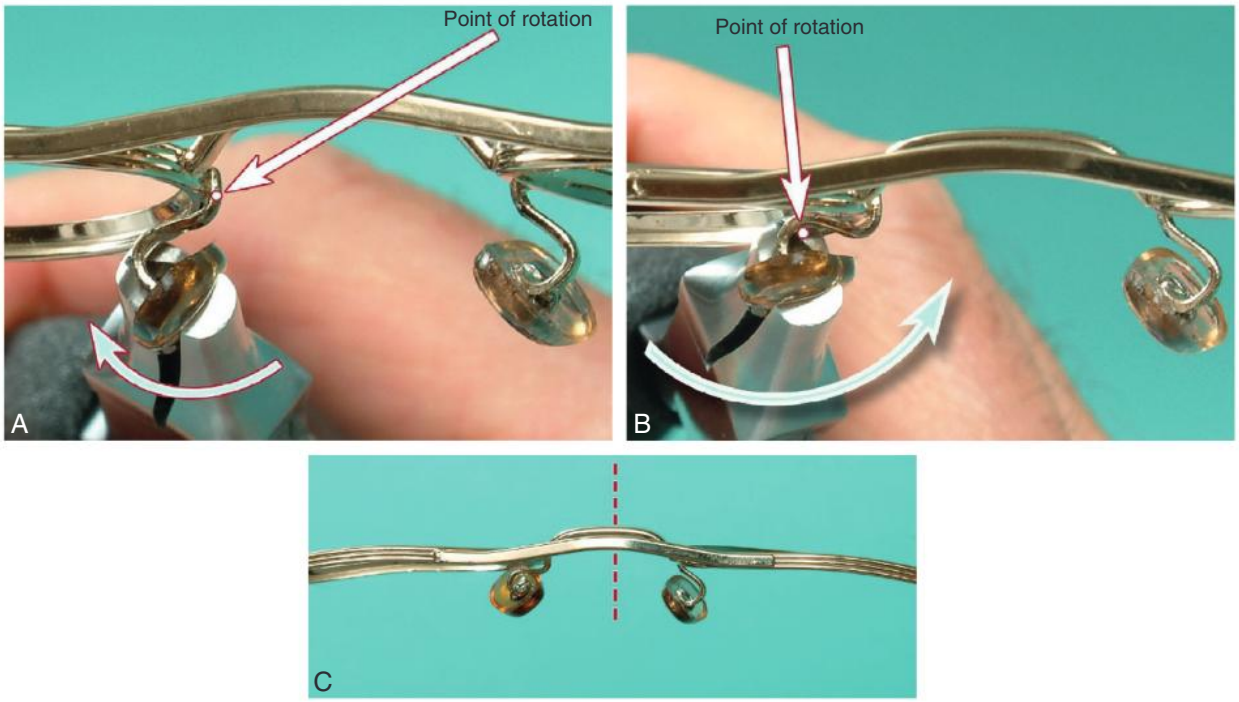


Figure 9.50 **A.** To widen the distance between pads for frames with question mark–style pad arms, there are two moves required. This sequence uses pad-adjusting pliers. The first move is to grasp the pad with the pad-adjusting pliers and bend the pad arm outward. The bend takes place at the pad arm's point of attachment. **B.** Here, for the second move in widening the distance between pads, the splay angle is corrected. The pad face is rotated as shown. **C.** The left pad has been moved to the widened position, but the right pad has not yet been adjusted. The center line is for reference so that the change in pad distance will be more readily evident.

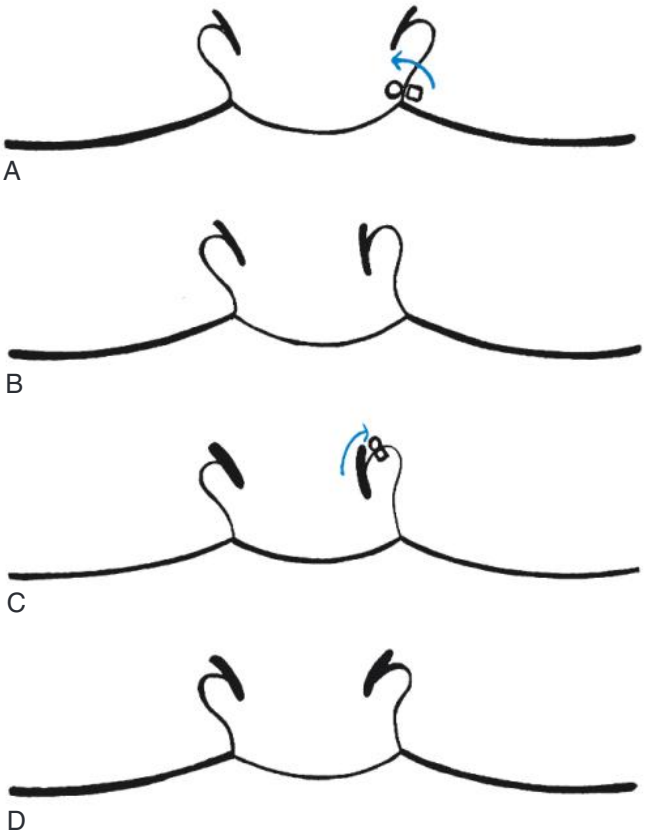


Figure 9.51 Summarization of the sequence of steps for narrowing the distance between pads with question mark-type pad arms. Only one pad is adjusted for the sake of comparison.

Suppose we change the question mark–style pad arms so they angle downward when leaving the eyewires instead of coming off at right angles. If the pads now rest on the same place on the nose as previously, the lenses will be situated higher on the face in relation to the eyes than previously. The reverse is true if the pad arms are angled up.

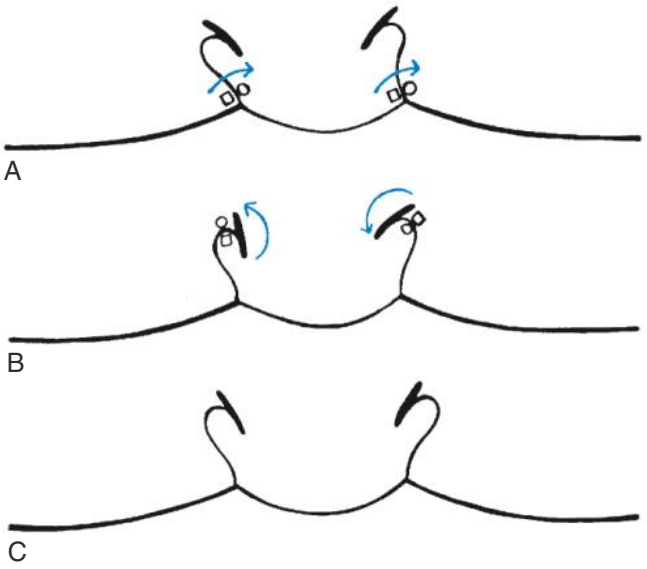


Figure 9.53 **A,** Even though both pad surfaces are correctly angled, both pads are too far to the left. This will cause the frame to be shifted to the right. Bending the pad arms back to their proper position throws the pad angles off **(B).** These must be re-angled as shown in **B** to achieve correct alignment **(C).**

Lowering the Frame: Question Mark Pad Arms

To lower the frame, the adjustment is done in two moves. The first bend moves the pad upward; the second corrects the messed-up vertical angle. Here is the procedure:

1. With the pliers held horizontally, grasp the entire pad arm between the pliers' jaws and simply bend the arm upward. (Figure 9.54, *A*, shows how the bend is done, and Figure 9.54, *B*, shows what the pad looks like after this first step is completed.)

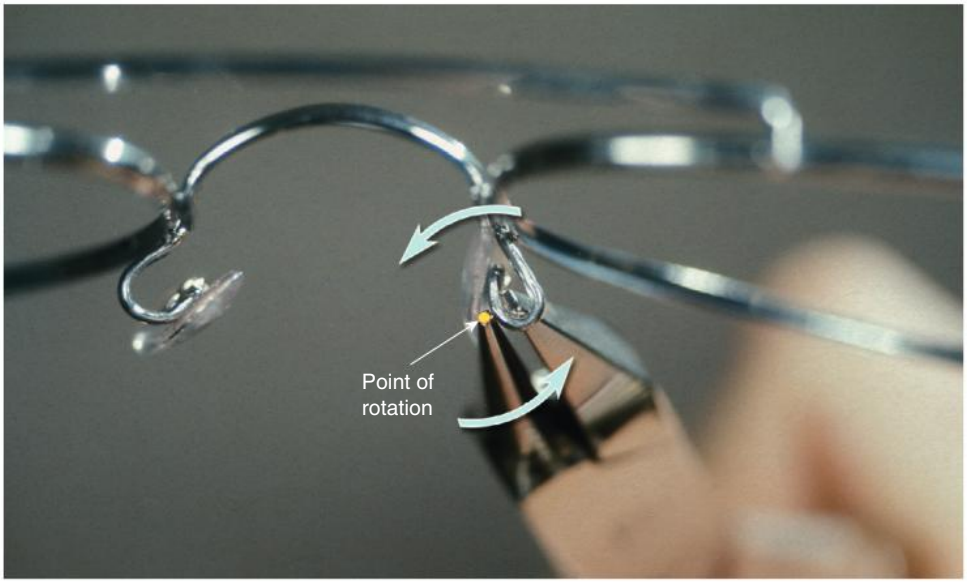


Figure 9.52 Square-round pliers being used to correct the splay angle of the nose pad and complete the pad narrowing process *(top view).* The point of rotation is at the center of the round jaw of the pliers.

Figure 9.54 **A**, To raise the pads on frames with question mark pad arms, thin pliers are used to grasp the entire pad arm and bend it upward. This will lower the frame on the face. **B,** After the question mark–type pad arm has been bent upward, the pad will be considerably higher but has an incorrect vertical angle. The pad must be re-angled. **C.,** Re-angling the pad to correct the vertical angle after having raised the question mark–style pad arm is done by grasping the curl close to the pad. This can be done with square-round (or thin-nosed) pliers as shown here. **D,** Note how much higher the pad on the right is than the pad on the left. When both pads are adjusted, the frame will sit considerably lower than previously.

Correct the vertical angle of the pad. To adjust the angle of the pad, use square-round pliers held vertically. Grasp the pad arm behind the pad halfway into the curl area and return the pad to its original angle (see Figure 9.54, *C* and *D*). It may be necessary to grasp the pad arm from above to complete the bend and to fully return the pad to the correct vertical angle.

2. Pad-adjusting pliers can also be used to correct the vertical angle if sufficient room between pad and eyewire is present and if care is taken not to accidentally bend the pad arm back to its original position.

Raising the Frame: Question Mark Pad Arms

To raise the frame, the sequence is the same as for lowering the frame with one exception—the pad arm is bent downward instead of upward. The procedure is:

1. With the pliers held horizontally, grasp the entire pad arm between the pliers' jaws and bend the pad arm downward.
2. Correct the vertical angle of the pad. To adjust the angle of the pad, use square-round pliers held vertically and grasp the pad arm behind the pad.

Increasing Only the Vertex Distance for Frames With Question Mark–Style Pad Arms

Extending the pad arms will increase the vertex distance between the lenses and the eyes. Here is the sequence of adjustments for frames with question mark–style pad arms:

1. *Open the pad arm curl.* Position the square-round pliers so that the square jaw is inside the pad arm curl and the round jaw is outside. Open out the curl of the pad arm by compressing the jaws and rotating the pliers slightly (Figure 9.55, *A*). This adjustment increases the distance from the lens to the pad.

   When a *radical* increase in vertex distance is necessary, it is possible to open the pad arm out completely (see Figure 9.55, *B*). This is

Figure 9.55 **A,** Increasing the vertex distance without changing frame height. To straighten the question mark–type pad arm, the curl of the arm is flattened by compressing the jaws and rotating the pliers slightly. Note the location of square and round jaws. Because the curl must open up some, the square jaw is on the inside of the curl (frame shown from below). **B,** Here the pad arm curl has been opened up and the pad faces back (frame shown from above). Note: Totally straightening the pad arm is not standard procedure. It is only done when a radical change in vertex distance is required. Normally the curl opens up somewhat but is not completely straightened. **C,** The splay angle is then corrected. In the case of a radical change in vertex distance, a new curl is placed in the pad arm closer to the pad so that the pad arm has a longer effective length. By noting the position of the square-round pliers in the photo, it is possible to predict the location of the new curl (frame shown from above). **D,** The pad arm on the left has been lengthened; that on the right is in its normal position (frame shown from above).

not standard procedure but may be done by squeezing a section of it at a time, gradually moving the positions of the jaws closer to the pad while squeezing with the large part of the pliers near the pliers' throat until the pad arm is absolutely straight.

2. *Replace the curl nearer to the pad.* Opening the curl of the pad arm, by whatever method, will turn the pad away from its proper angle.

In a radical adjustment, the pad surface faces straight back or nearly so. The pad arm will now require a new curl, which should be placed closer to the pad than it was previously. To put the curl in correctly, hold the square-round pliers vertically, and grip the pad arm at the desired position of the curl. Position the round jaw so that it will be on the inside of the new curl (see Figure 9.55, *C*). Using the round jaw as a pivotal point, rotate the pliers until the pad reaches its proper position. Figure 9.55, *D*, shows an example of how the pad arm should look when finished.

Decreasing Only the Vertex Distance for Frames With Question Mark–Style Pad Arms

Bringing the pads closer to the lenses will decrease the vertex distance. Here is the two-step sequence used to bring about this change for pad bridges with question mark–style pad arms. (See Figure 9.56, *A*, to see what the pads look like before starting the adjustment.)

1. Grasp the pad arm at its base with the round jaw toward the temporal side of the frame (see Figure 9.56, *B*). Bend the pad arm toward the lens. This will throw the splay angle off (see Figure 9.56, *C*).
2. Position the square-round pliers in the curl of the pad arm with the round jaw on the inside of the curl (see Figure 9.56, *D*). Tighten the curl by rotating the pliers around the round jaw. This should move the pad closer to the frame, correct the splay angle, and return the pad to the original distance between pads.

When the adjustment is complete, the re-angled pad should duplicate its original angle (see Figure 9.56, *E*).

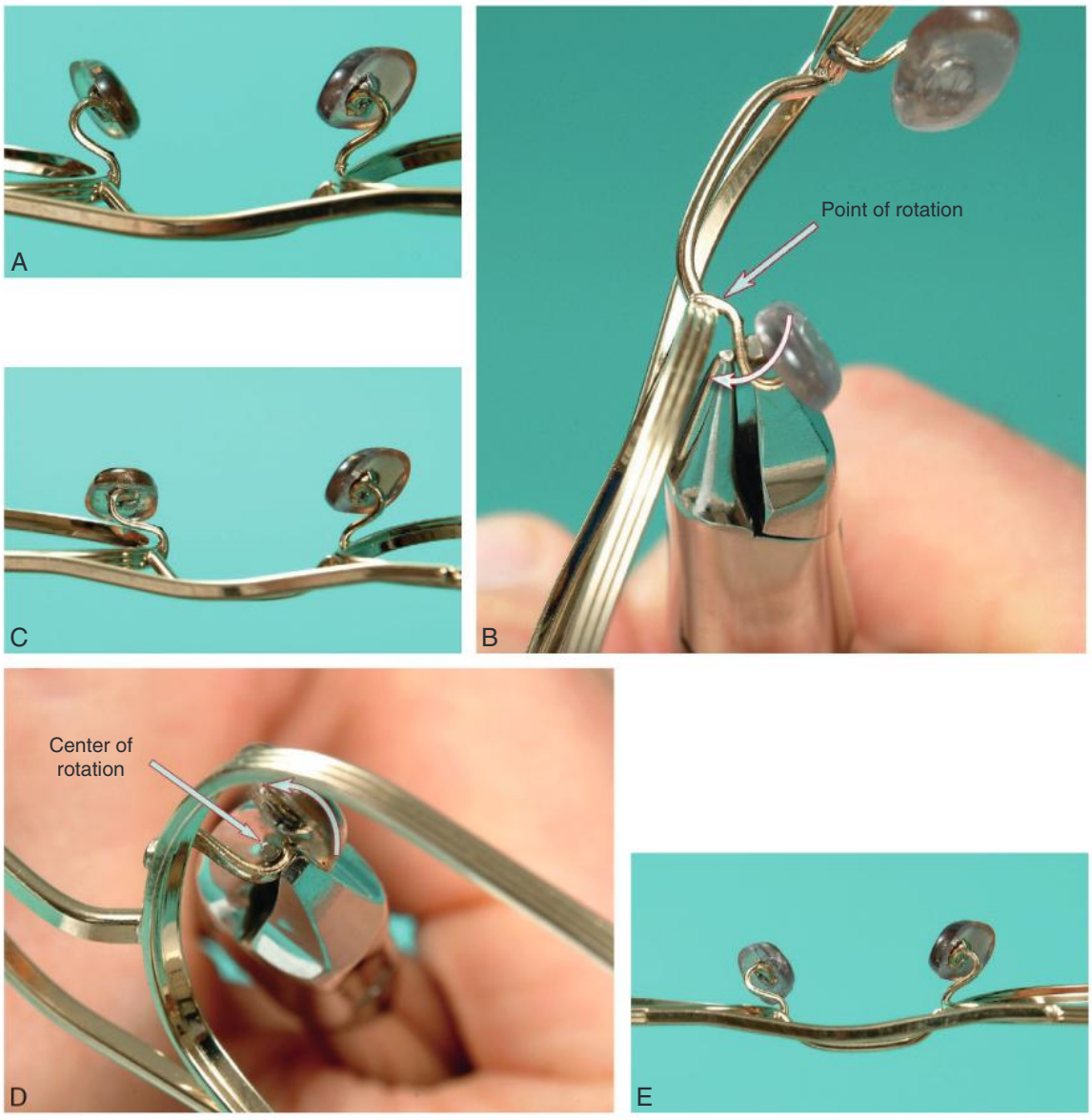


Figure 9.56 **A,** Here is how the pads and pad arms appear before shortening the effective length of the pad arms. This will decrease the vertex distance from frame to eyes. The pad on the left will be moved (frame shown from above). **B,** To decrease the vertex distance, bend the pad arm temporally. The bend takes place at the point of attachment of the pad arm (frame shown from below). **C,** The pad arm on the left has been bent outward at the base in the first part of the procedure for decreasing the vertex distance. The splay angle has been thrown off (frame shown from above). **D,** To complete the decrease in vertex distance, tighten the curl of the pad arm. This moves the pad closer to the frame, corrects the splay angle, and returns it to where the distance between pads will be the same as it was before. Note that the square-round pliers grasp the curl with the round jaw on the inside of the curl (frame shown from a front view and from below). **E,** The pad arm on the left has been effectively shortened. The pad arm on the right is positioned normally. After the pad arm on the right has been adjusted, the vertex distance will be considerably less than before (frame shown from above).

RECHECKING THE FRAME FIT

After completing the steps in fitting the frame as given in this chapter and as summarized in Box 9.2, recheck the following before considering the fit final.

Final Frame Adjustment

1. Are the glasses positioned at the correct height vertically?
2. Is one lens or one multifocal segment higher than the other? Are progressive lens fitting crosses directly in front of the pupils?
3. Is the pantoscopic tilt correct?
4. Are right and left vertex distances equal?
5. Is the temple pressure along the side of the skull correct?
6. Is the temple bend positioned correctly relative to the tops of the ears?
7. Does the bent-down portion of the temple angle downward correctly?

BOX 9.2 Steps in Fitting

Step 1: Temple/endpiece angle
a. Check for proper temple-spread angle.
b. Check for equality of lens distances from the eyes, viewing from the top.
Step 2: Pantoscopic angle
a. Check tilt of lenses from a side view.
b. Check for straightness of the frame on the face from a front view.
Step 3: Nose pads or bridge area
a. Adjust the frame for proper height when necessary.
b. Adjust the frame for proper vertex distance when necessary.
c. Adjust nose pads for maximum surface contact.
Step 4: Temples
a. Temples are adjusted to exert slight pressure over the tops of the ears.
b. The temple bend is moved to its proper position when necessary.
c. The bent-down portion is contoured to match the side of the head and back of the ear.

After the fitter gains experience, it will be found that many of the steps can be done simultaneously because it will be possible to see and correct more than one thing at a time.

BOX 9.3 Summary of Adjustments for Moving the Frame on the Face

To move frame away from face/eyes:
1. Narrow adjustable pads (also raises frame).
2. Increase effective length of pad arms.
3. Decrease face form (make frame front straighter).

To move frame closer to face/eyes:
1. Spread adjustable pads apart (also lowers frame).
2. Decrease effective length of pad arms.
3. Increase face form (make front more curved).

To move frame off the cheeks:
1. Decrease pantoscopic tilt.
2. Raise the frame by narrowing the distance between pads or bending pad arms down.
3. Increase vertex distance by narrowing distance between pads or extending the effective length of the pad arms.

To move frame from off the brows:
1. Increase pantoscopic tilt.
2. Lower the frame by widening the distance between pads or by raising the pad position.
3. Increase vertex distance by extending pad arm effective length. (Note: attempting to move frame forward by narrowing the distance between pads is likely to raise it further.)

To move frame higher on face:
1. Narrow the distance between adjustable pads.
2. Lower the vertical position of adjustable pads.
3. Add pads to plastic bridge (see Chapter 10).

To move frame lower on face:
1. Increase the distance between adjustable pads.
2. Raise the vertical position of adjustable pads.

To move one lens closer to (and the other farther from) the face:
1. If left lens is IN, bring left temple IN, and/or if right lens is OUT, bring right temple OUT.
2. If right lens is IN, bring right temple IN, and/or if left lens is OUT, bring left temple OUT.

To move one lens higher (and the other lower) on the face:
1. If left lens is UP, bend left temple UP, and/or if right lens is DOWN, bend right temple DOWN.
2. If right lens is UP, bend right temple UP, and/or if left lens is DOWN, bend left temple DOWN.

8. Do both right and left bent-down portions of the temples follow the contour of the side of the head? (In other words, does the posterior portion of the temple need to be formed to follow the curvature of the side of the head?)

Nose Pad Rechecks

1. Is the distance between pads correct for the wearer?
2. Are the pads sitting on the correct part of the nose for the wearer?
3. Do the frontal angles of the pads correspond to the frontal angles of the wearer's nose?
4. Do the splay angles of the pads correspond to the splay angles of the wearer's nose?
5. Are the long axes of the pads perpendicular to the floor? (In other words, does the vertical angle of the pad equal the pantoscopic angle of the frame front when the glasses are being worn?)
6. Overall, do the pads sit flat on the surface of the nose?

For a summary of adjustments on how to move the position of the frame on the face, see Box 9.3.

The Overall Fit

Test for equality of temple tension on each side by lifting the temples off the ears slightly and pulling the front forward gently. Equality of temple adjustment can also be checked by placing the thumbs on the sides of the temples of the frame and the fingers directly behind the wearer's ears (between the back of the ear and the bent-down portion of the temple). Do this simultaneously for both ears, using both hands, to obtain an accurate estimate of equality of adjustment.

The wearer should put the glasses on and take them off several times to see if they rest in the proper place. This exercise will reveal if the wearer puts his glasses on in such a way that they rest in some unusual manner, such as with the temples high on the head or in the hair. In such cases, if the person sincerely intends to wear the glasses in an unconventional manner, it may be necessary to alter the frame adjustment.

Make known any deliberate irregularities in the glasses, such as unequal seg height or pantoscopic angles. If attention is not specifically called to these irregularities, the wearer is often mistakenly left with the impression that something is wrong with the glasses.

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1. Kintner EA. The Relative Role of Physical Features of Spectacles as Factors in Wearing Comfort. Master's Thesis, Bloomington, IN: Indiana University; 1970.
2. Stimson RL. Ophthalmic Dispensing. 2nd ed. Springfield, IL: Charles C Thomas; 1971.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. Which of the following may *not* be a cause of one lens being higher than the other?
   a. one earpiece being bent down further than the other
   b. an upward bend in one of the temple shafts
   c. a skewed bridge
   d. one ear higher than the other
   e. nose pads spread too far
2. If the frame is crooked with the right side higher than the left:
   a. bend the right temple down
   b. bend the right temple up
3. A bifocal wearer complains that the bifocal line is too high. The frame has adjustable nose pads. Assuming that cosmetics will allow, what could be done to alleviate the problem?
   a. Decrease the distance between pads.
   b. Increase the distance between pads.
4. Which is *not* a possible *solution* for the frame sitting too high on the face?
   a. increase the distance between adjustable nose pads
   b. move the vertical position of adjustable nose pads downward
   c. choose a different frame
5. If the eyelashes rub the back surface of the lenses, the fitter should:
   a. spread the temples.
   b. raise the frame.
   c. increase the vertex distance.
   d. spread the nose pads.
6. Which of the following is not a possible cause of *both* lashes touching the lenses?
   a. not enough pantoscopic tilt
   b. base curves that are too flat
   c. adjustable nose pads that are positioned too close to the frame front
   d. adjustable nose pads that are too close together
7. If the top of the frame front touches the eyebrows, what is *not* a possible solution to the problem?
   a. choosing a different frame
   b. moving the adjustable nose pads farther away from the frame front
   c. increasing the pantoscopic angle
   d. All of the above are possible solutions to the problem.
8. One lens is closer to the wearer's face than the other. How could this be corrected?
   a. Increase the pantoscopic tilt on the side closest to the face.
   b. Increase the temple spread (bend the temple outward) on the side closest to the face.
   c. Decrease the temple spread (bend the temple inward) on the side closest to the face.
   d. Tighten the temple tension behind the ear on the side farthest from the face.
9. If the wearer complains that the glasses feel snug but still slip down the nose, one likely cause is that:
   a. the bridge size is too large.
   b. the bridge size is too small.
   c. too much pressure is being applied by the temple shafts on the sides of the head in front of the ears.
   d. too much pressure is being applied to the sides of the head behind the ears by the very tips of the temples; no pressure is being applied to the sides of the head in front of the ears.
10. True or false? Narrowing the distance between adjustable nose pads causes the frame to sit higher on the face and somewhat closer to the face.
    a. True
    b. False
11. True or false? Strap bridges are a replacement for adjustable nose pads. They help increase the weight-bearing area. Unfortunately, they are not adjustable like the pads they replace.
    a. True
    b. False
12. The wearer has a crooked nose from a previous fracture. The new frame has an adjustable pad bridge. When the glasses are put on the wearer, the frame front sits too far to the wearer's left. (Any references to left or right in the responses below are from the wearer's point of view.) What should be done to correct the problem?
    a. Move both right and left pads to the right.
    b. Move both right and left pads to the left.
    c. Move the right pad to the right and the left pad to the left.
    d. Move the right pad to the left and the left pad to the right.
13. When viewing the wearer from the front, it is discovered that the frame sits too far to the wearer's right. What might be causing this?
    a. Both pads are too far to the wearer's left.
    b. Both pads are too far to the wearer's right.
    c. The wearer's nose is crooked.
    d. Both a and c are possible causes.
    e. Both b and c are possible causes.
14. True or false? The wearer is looking straight ahead. If the dispenser views the glasses from the side and the nose pads are properly adjusted, the long axis of the pads should be perpendicular to the floor.
    a. True
    b. False
15. True or false? Most pad adjustments may be done in two movements. The first move makes the change; the second move completes the change and/or restores the proper pad angle.
    a. True
    b. False
16. If *both* nose pads press flat against the side of the nose yet hurt or cause indentations on the nose, what is a possible cause?
    a. The temple spread is not even.
    b. The pads need to be spread farther apart.
    c. The pads are too small for the weight of the frame.
17. Where should the tip of the temple be located in a cable temple that is correctly fitted?
    a. at the lower lobe of the ear
    b. slightly past the lower lobe of the ear
    c. just short of the lower lobe of the ear
18. Which of the following statements about temples with good quality spring hinges is false?
    a. Frames with spring hinges are less likely to require readjustment or repair when struck with a ball or an elbow or when knocked from the face.
    b. Spring temples are adjusted behind the ears exactly as any other temples would be.
    c. The temple bend location is positioned exactly the same for spring hinge temples as for temples without spring hinges.
    d. Frames with spring hinges should be adjusted so they are tighter than frames with normal, well-fitted temples.

19. True or false? When choosing a frame for individuals with behind-the-ear hearing aids, the best temple design is one that is thin and conforms nicely to the side of the head or, in the case of cable temples, to the back of the crotch of the ear.
    a. True
    b. False
20. True or false? Here is the procedure for taking off a pair of glasses that have cable temples. The wearer should grasp the left endpiece with the left hand and the tip end of the right cable temple with the right hand. The right temple is pulled off the ear and the glasses swung to the left so that the left cable temple comes off the ear easily without causing the glasses to lose their adjustment.
    a. True
    b. False
21. The temples on a frame do not open the same amount. One has a greater temple spread than the other. When this is the case, the lens that will be closer to the eye will be the lens:
    a. on the same side as the looser (more widely spread) temple.
    b. on the same side as the tighter (less widely spread) temple.
22. The temples on a frame do not open the same amount. One has a greater temple spread than the other. When this is the case, the side of the nose that could become irritated is:
    a. on the same side as the looser temple.
    b. on the same side as the tighter temple.
23. The temples on a frame do not open the same amount. One has a greater temple spread than the other. When this is the case, the ear that is likely to become irritated will be:
    a. the ear on the opposite side of the tighter temple.
    b. the ear on the same side as the tighter temple.
24. When a wearer's frames are both slipping down the nose and hurting behind the ears, the most probable solution would be to:
    a. move the temple bend farther forward on the temple.
    b. move the temple bend farther back on the temple.
    c. increase the temple spread.
    d. decrease the bridge size.
    e. angle the tips of the temples inward.
25. A wearer comes into the office. His frames are out of adjustment. The left lower rim touches his left cheek, and the right side of the frame front is higher than the left side. It also appears that there is just a bit too much pantoscopic angle on the frame. Given the choices below, if you can only make one choice, which choice would be the best?
    a. Bend the left temple upward.
    b. Bend the left temple downward.
    c. Bend the right temple upward.
    d. Bend the right temple downward.
    e. Bend the left temple upward and the right temple downward.
26. Which of the following problems would not be helped or solved by widening the distance between nose pads?
    a. The frame is too high on the face.
    b. The bridge is somewhat small for the nose.
    c. The lashes rub the back surface of the lenses.
    d. All of the above problems would be helped or solved by widening the frame bridge.
27. When being worn, the only appropriate place for eyeglasses to exert pressure is:
    a. on the sides of the head at the very ends of the temples.
    b. on the sides of the head directly above the ears.
    c. in the crease between the back of the ear and the side of the head.
    d. There should never be any pressure exerted by the frame.
28. True or false? Attempts to conform the temple earpiece to follow the depression in the side of the head behind the ear do not result in enough improvement in fit to make fitting efforts worthwhile.
    a. True
    b. False
29. Contemporary frames having spring hinge temples should be adjusted so that:
    a. the temple pressure against the sides of the head is considerably less than for frames without spring hinges.
    b. the temple pressure against the sides of the head is slightly less than for frames without spring hinges.
    c. the temple pressure against the sides of the head is the same as for frames without spring hinges.
    d. the temple pressure against the sides of the head is slightly greater than for frames without spring hinges.
    e. the temple pressure against the sides of the head is considerably greater than for frames without spring hinges.
30. If the front edge of the pad cuts in and makes a vertical red mark on the nose and you wish to correct the problem,
    a. increase the frontal angle of the pads.
    b. decrease the vertical angle of the pads.
    c. decrease the frontal angle of the pads.
    d. decrease the splay angle of the pads.
    e. increase the distance between pads.

10

Frame Repairs and Modifications

SCREW REPLACEMENTS AND REPAIRS

Most major frame repairs require a lot of time. As a result, replacement of broken parts is usually more cost-effective. Occasionally, however, a major repair can provide a vital service to a wearer if it enables the continued wearing of a much-needed prescription.

Minor repairs also take time but usually not more than would be expended in aligning a new pair of glasses. Perhaps, more important, is how much these repairs are appreciated.

This chapter begins with the two most common problems: screw repairs and nose pad replacements, followed by the third most common problem, temple repairs.

Correctly Using an Optical Screwdriver

When using an optical screwdriver, the screwdriver should *not* be held like a pencil (Figure 10.1). Instead, place the handle end in the palm of the hand, as shown in Figure 10.2, *A*. (Typically the end of the handle is made to rotate, making this technique work more smoothly.) Grasp the screwdriver, as shown in Figure 10.2, *B*. Now brace the frame on the edge of the workbench (Figure 10.3) or on a bench block so that if (or rather *when*) the screwdriver slips, the sharp tip will not go halfway into your finger.

A Note on Screwdriver Types

There are many different types of optical screwdrivers available, from ones with brass shafts and no-roll handles to others having large, round hardwood handles that fill the palm of the hand. There is also an ergonomic type shown in Figure 10.4 with a handle that can be bent to conform to the hand.

It can be tricky enough just to hold a tiny screw between the thumb and forefinger. Getting it screwed into the hole far enough to get it started is even harder. Here are two options to help in this matter.

- There is a "pick-up" screwdriver with spring-loaded retractable jaws for holding small screws until they catch the threads in the barrel.
- Another option is a special screw-holding tool that grips the screw so that it can be more easily pressed into the hole (Figure 10.5).

Check to make sure that the blade of the screwdriver is in good condition. Damaged blades can damage screw heads. Regardless of what screwdriver is used, the blade size needs to match the screw. (Most optical screwdrivers have reversible blades with different widths on each end.)

Another helpful tool is a screw-lift tool. This is used after the screw is loose and ready to be removed. This tool is used to lift the screw from the hole without dropping and losing it (Figure 10.6).

Loose Screws

The constant opening and closing of temples sometimes turns the temple screw and loosens it. Although a loose temple does not necessarily affect the fit or stability of the glasses, most wearers would like to see the problem fixed. If the screw is loose and has not been fully turned, simply tighten it. Overtightening may either break the screw or cause the temples to bind, requiring the temples to be forced shut. The screw should be just tight enough so that when the glasses are held with the front downward, the upward-pointing temples will not drop closed past a 45-degree angle on their own.[1]

Sometimes, even after tightening a temple screw, the temple may still be loose and floppy. In this case, the temple barrels may need to be realigned. Realignment of temple barrels is discussed later in the *Misaligned Hinge Barrels* section.

Using a Sealant to Keep Screws Tight

One solution for a screw that continually loosens is to use a screw-locking adhesive sealant on the screw threads to hold it tight. A sealant not only keeps the screw from loosening, it also keeps it from corroding. A corroded screw will lock up over time, making removal difficult. Most optical suppliers carry these products.

Some prefer to use clear nail polish instead of a sealant, painting the head of the screw and the threads to prevent turning. This method is most successful on screws located in a recessed position and permits easy removal of the screw later (Figure 10.7).

Peening Screw Tips to Keep Screws Tight

For temple screws whose tips protrude beyond the barrels, it is possible to put a rivet-like head on the end of the screw. This can be done in one of several ways including:

1. Tapping the tip of the screw firmly with the small end of an optician's hammer to keep the screw from backing out;
2. Using flaring pliers designed to flare out the ends of the screws and rivets (Figure 10.8); and
3. Peening down the end, using a staking set with the concave-end peening tool. Once the tip of the screw has been flared, it will be necessary to file the tip in order to remove the screw.

Using Replacement Self-Locking Screws to Keep Screws Tight

Self-locking replacement screws have an epoxy type of coating on the threads that keeps the screw from backing out (Figure 10.9). These screws can be removed and used again as when an eyewire screw must be removed and reinserted when changing lenses.

The preceding methods of keeping screws tight are summarized in Box 10.1.

Other Methods Used to Keep Screws Tight

Some frames have built-in systems to keep the screws in place. These frames are designed with a small setscrew in the side of one of the barrels or with a small nut that grasps the tip of the protruding screw.

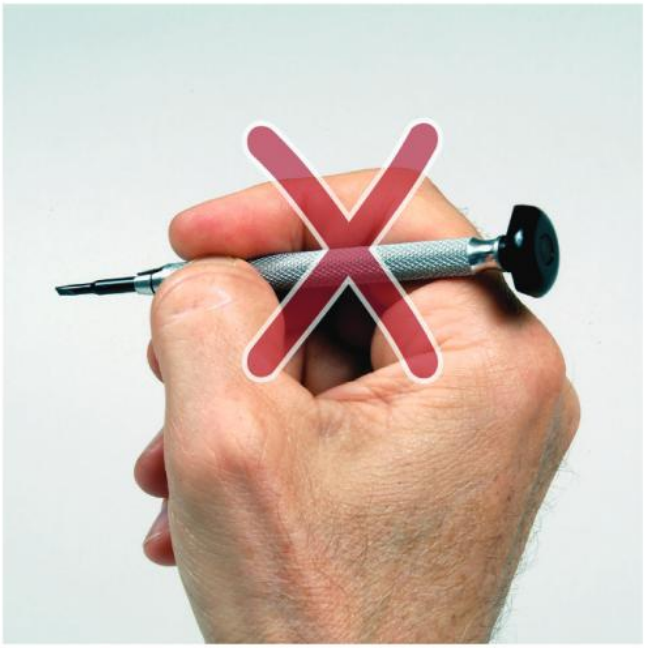

Figure 10.1 This is the wrong way to hold a screwdriver.

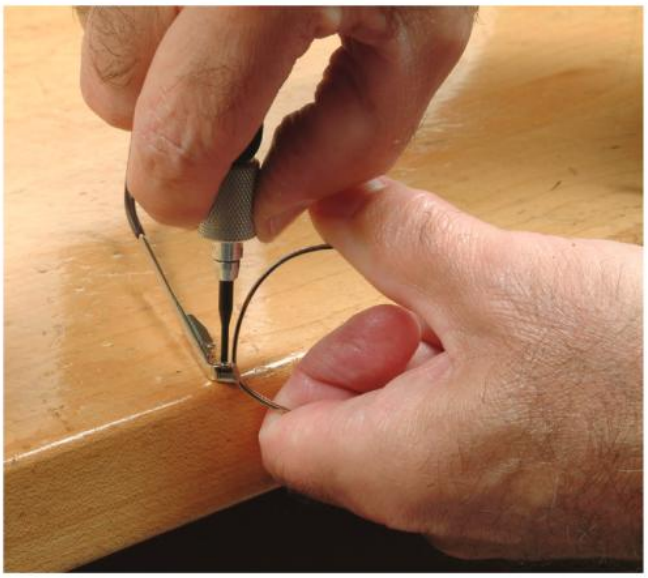

Figure 10.3 Safety first. Always brace the frame against something. Do not hold the frame so that when (not if, but when) the screwdriver slips, it will not penetrate your other hand.

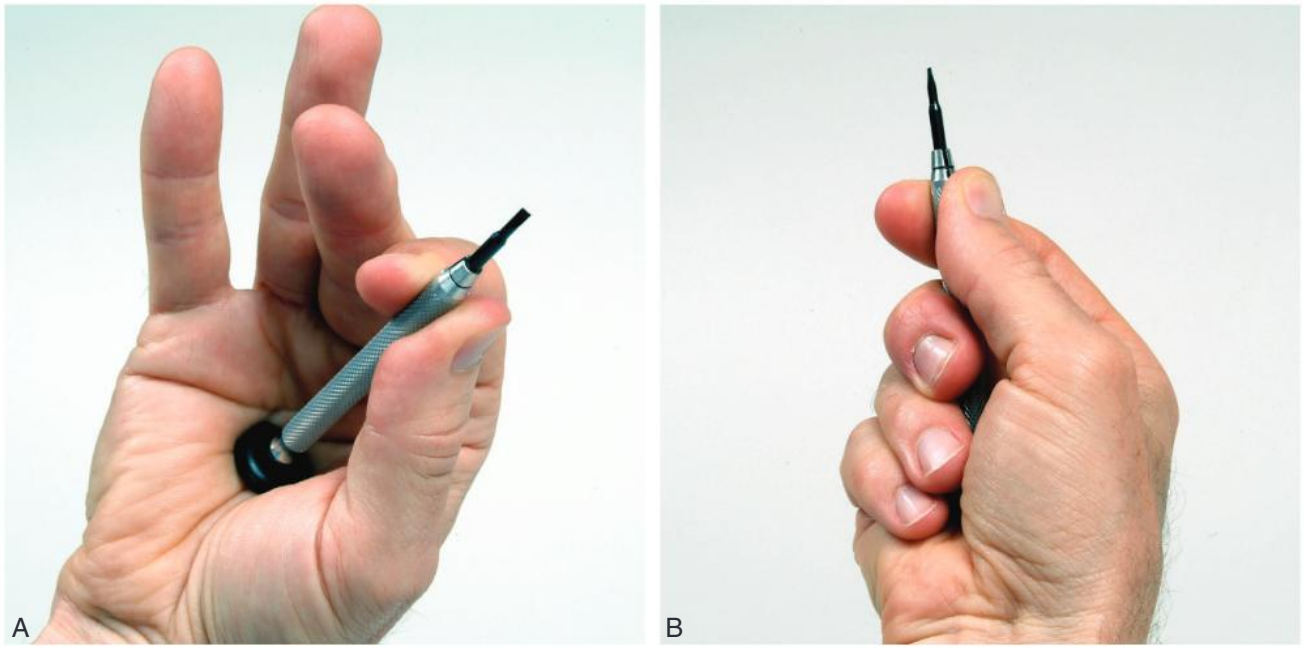

Figure 10.2 **A,** This photo shows how to grasp the optical screwdriver so that the rotating end of the handle is in the palm of the hand. **B,** With the handle end cradled in the centre of the palm, grasp the optical screwdriver as shown.

Replacing a Spring Hinge Screw

In many spring hinges, the screw holds the spring within the temple in tension. When the temple is off the frame front, the screw hole on the temple spring is somewhat recessed into the temple. The hole is visible, but because it is recessed, it will not evenly line up with the hinge barrels on the frame front's endpiece. Because of this, it is difficult to line up the barrels on the endpiece with the barrel on the temple when replacing the temple screw. Unless some special tools or specialty screws are used, accomplishing a screw replacement may be difficult.

Replacement Screws for Spring Hinges

When attempting to insert a screw and turn it into place when the temple barrel is still somewhat recessed, the barrels don't line up, and the screw will only go in at an angle instead of straight up and down. If the screw is screwed in at an angle anyway, it is likely to strip the threads in the barrel. To avoid this, Hilco makes a self-aligning spring hinge screw. This stainless-steel screw is longer, has a tapered tip, and a Tight Bond™ locking coating to help hold the screw in place. The tip is small enough to go through the barrels, even though they don't line up with

Figure 10.4 There are a large variety of optical screwdrivers available, including this ergonometric one that bends to find the size and shape of the hand.

Figure 10.5 The screw-holding tool places the screw in hard-to-reach places where fingers cannot always go.

Figure 10.6 The screw-lift tool allows a loosened screw to be removed with less chance of being dropped.

each other. The screw remains straight up and down, and the narrow tip acts as a lead to align the hinge barrels as the screw is screwed into place (Figure 10.10).

Once the screw is seated, the excess length of the screw that sticks out can be snapped off with regular pliers. Cutting pliers are not needed

Figure 10.7 Use clear nail polish to seal a tightened screw in place and prevent it from loosening up. This combination frame has an eyewire screw recessed under the top rim.

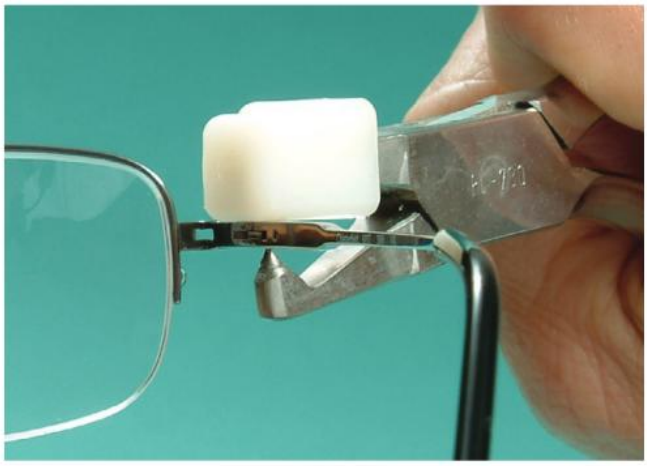

Figure 10.8 Flaring pliers will flare a rivet or screw tip to prevent it from backing out.

Figure 10.9 This type of self-locking replacement screw has an epoxy type of coating on the threads that keeps the screw from backing out. The screw is removable and can be used again. As would be expected, each time it is taken out and reinserted, it loses some of its adhesive characteristics.

and should not be used. The screw is made to break practically flush with the barrel. The broken end of the screw may be peened down with peening pliers or a staking tool for a neater look and more secure hold.

Using a self-aligning spring hinge screw may be the most straightforward method for putting the spring hinge temple back on the frame front while requiring the least amount of practice.

Once the screw is in place, flex the temple outward to see how good the action on the spring temple is. If it opens but does not spring back as it should, you may need to either:

BOX 10.1 How to Keep a Loose Screw in Place

1. Use a sealant on the threads and in the barrel.
2. Use clear nail polish on the head, especially if the head is in a recessed area.
3. Flatten or peen the tip of the screw.
   a. Use an optician's hammer.
   b. Use flaring (peening) pliers.
   c. Use a staking set with a peening tool.
4. Use self-locking replacement screws.

Spring hinge screw

Figure 10.10 The spring hinge screw is tapered at the tip. This allows the screw to more easily slip into the small open area between the non-aligning temple and frame front barrel holes. This screw, available in gold, silver, or black, comes in a variety of sizes and has a locking coating to help keep it from backing out over time. (Courtesy of Hilco, Plainville, Mass.)

1. Loosen the screw slightly. The tension of the tight screw may be holding it open.
2. Use some lubricating oil, such as "3-in-1," which may help in keeping the spring working well without sticking.

SnapIt Screw

An alternative to the Hilco self-aligning spring hinge screw is the SnapIt screw. This is a screw with a long, narrow extension on the end of the screw as shown in Figure 10.11. It works in much the same way as the Hilco screw, has a Stay-Tight™ thread lock, and has a longer extension so that it may be snapped off using the fingers instead of pliers. The clean snap does not require filing. SnapIt screws were originally made as an easy-to-use replacement for regular hinge and eyewire barrel screws that could be sold directly to the public as kits. OptiSource has a wide variety of SnapIt sizes and colors compatible with prescription optical frames. SnapIt screws may be used as a replacement for most any hinge or eyewire screw.

Spring Hinge Alignment Tools

Because of the difficulty of putting a spring hinge temple back on a frame while inserting the screw in the temple, several types of spring hinge alignment tools have been developed. Here is how to use one such tool.

Figure 10.12 shows how the barrels in the temple and frame front do not line up exactly. The spring in the temple is not stretched to allow the hole in the temple barrel to line up with the holes in the barrels on the frame front.

There are two parts to this spring hinge alignment tool. One part is a tiny "wrench" with a small tip on the end (Figure 10.13). The tip fits into the temple barrel hole to pull the barrel and extend the spring as shown in Figure 10.14, *A* and *B*. (These two figures are for demonstration purposes only and are not a part of the screw replacement process.)

The second part of the tool is shown in Figure 10.15. It has a slide that will lock it in place after the tool has a grip on the temple. There is also the small "tooth" on the angled head of the tool. Here is the procedure:

Figure 10.11 The SnapIt Screw was originally developed as a replacement for regular hinge and eyewire barrels but is also used for spring hinges. It comes in a variety of sizes and colors. Because of its ease of use, it has developed a following among eye care practitioners. The top screw is how the screw comes. The bottom screw shows how smoothly the bottom will snap off. (From OptiSource. http://www.1-800-optisource.com/Silver-Flat-Head-Snapit-Screws.aspx Used by permission.)

Figure 10.12 This picture shows that when spring hinge temples are placed on the frame front, their barrel holes do not line up. They do not line up because the spring in the temple is not stretched.

1. Put the temple in the tool with the head of the tool behind the barrel and at the front of the casing that surrounds the spring hinge.
2. Place the wrench in the barrel hole and extend the barrel (Figure 10.16). Most spring hinge casings are notched as shown in the figure. Thus the "tooth" slips into the notch. This holds the barrel in its extended position. (Note: Some casings do not have a notch. For this kind of temple, the angled head of the tool is used to grip the flat front of the casing and not the "tooth.")
3. Hold the tool tightly, and move the slide forward to maintain a solid grip on the temple (Figure 10.17).
4. Now the temple barrel can be slipped into the barrels on the frame front. They will line up as a regular temple would.
5. The screw may now be placed into the barrels and tightened (Figure 10.18).

It should be noted that it is possible to carry out the above procedure without a spring hinge aligning tool. Instead, some have used a push pin (as normally used with bulletin boards) to pull the barrel out. Then a second push pin or a paper clip is placed in the exposed notch to hold the extended spring hinge in place while the temple is reattached. This takes more skill and patience to do, but it is possible.

There are different styles of spring hinge alignment tools. Another type is the Hilco Spring Hinge Tool Kit shown in Figure 10.19.

Misaligned Hinge Barrels

When a temple is still loose even after tightening the screw, the problem may be that the barrels of either the frame endpiece or temple hinges are bent slightly. To correct this problem, remove the screw and the temple. Note which set of hinge barrels has the greater number of barrels. Use parallel-jawed pliers, such as hollow-snipe pliers, to compress the barrels of this front hinge to slightly narrow the spaces between barrels (Figure 10.20). Do not compress the barrels too much or the other set of barrels will not fit, and then the compressed barrels have to be pried apart, which risks breaking off a barrel.

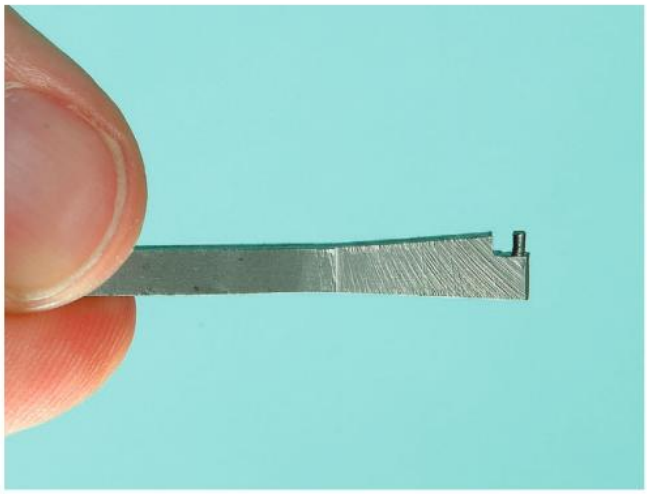

Figure 10.13 This is the "wrench" used with one type of spring hinge alignment tool. The small tip on the end slips into the spring hinge barrel.

In some instances, the barrels can be compressed with the screw removed but both sets of barrels still fitted together and not taken apart. This is worth trying but is difficult and usually unsuccessful.

Replacing a Missing Screw

The most difficult aspect of replacing a missing screw is finding the right-sized replacement. Fortunately, the industry is gravitating to a common screw diameter of 1.4 mm and a length of 3.0 to 4.0 mm.

Table 10.1 shows the most common sizes of replacement screws for regular spectacle frames, quality sunglasses, over-the-counter sunglasses, nose pads, and trim.

For the more unusual sizes, Hilco makes a Fast-Find Screw and Hole Gauge Set that includes a screw gauge, a hole gauge, and a booklet with screw dimensions. These gauges allow one to easily match an existing screw or quickly find the dimensions of a missing screw using the frame.

To Find the Size of an Existing Screw

To find the size of an existing screw, first measure the diameter. This is done by putting the screw through the presized holes on the ruler-like device as shown in Figure 10.21. Next, measure the overall length of the screw, including the head, using the slots on the same device.

To Find the Size of a Missing Screw

To find the needed size of a missing screw, start with the length. To find the length of a missing screw, use the slots on the ruler-type device to measure the depth of the barrels as shown in Figure 10.22, compensating an additional amount for the screw head. (Measure either the barrels on the frame front or the temple, depending on which set of barrels is largest. In the figure shown, the set on the temple is larger.)

To find the diameter of the missing screw, use the round, spoke tool. Each spoke has a different diameter. These spokes are inserted into the empty barrel of the frame to find the unknown diameter as shown in Figure 10.23.

Finding a Screw from Inventory

One of the more frustrating aspects of screw replacement is just finding a matching screw. Without an organized system, the dispenser is reduced to searching through a tray or jar full of extremely small screws, all of which begin to look like one another. Many eye care

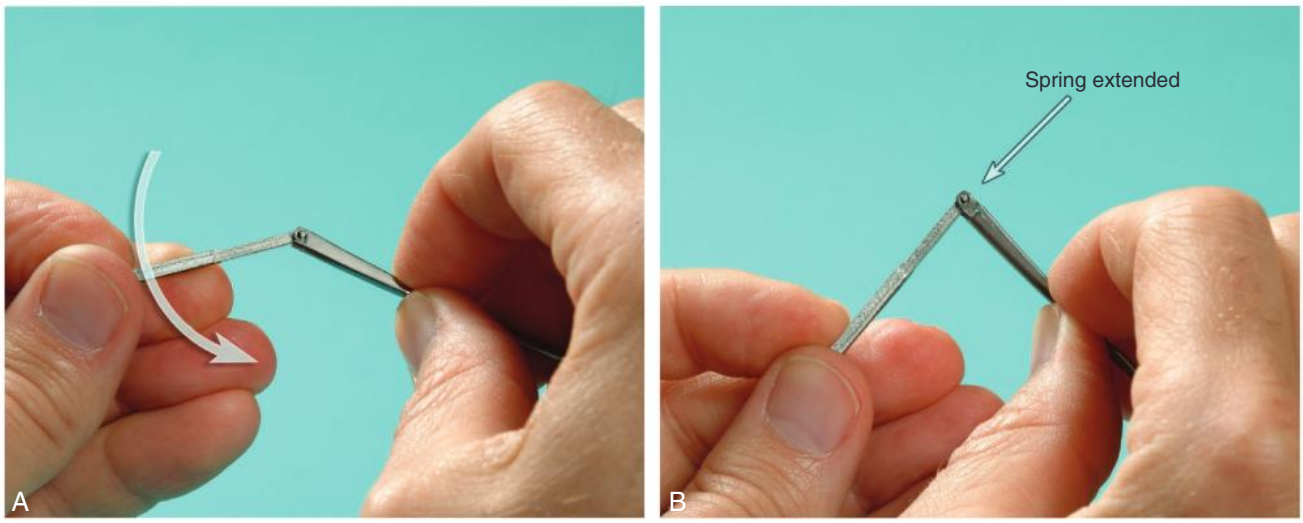

Figure 10.14 **A,** The "wrench" slips into the temple barrel and will extend the spring. **B,** Here the spring in a spring hinge temple has been extended. Note how far it has been pulled out compared with the previous figure.

Figure 10.15 This part of the spring hinge alignment tool grasps the temple. The "tooth" on the end will slip into the notch on a notched spring hinge casing. The tooth will hold the spring in the extended position. For spring hinge casings without a notch (called *flat front casings*), the angled head of the tool holds the barrel in the extended position.

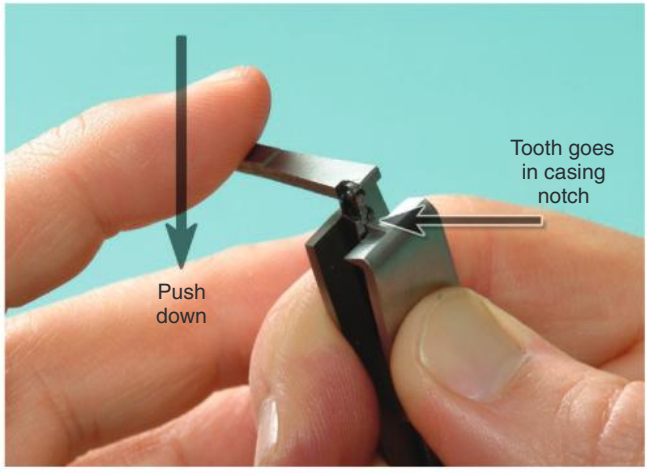

Figure 10.16 The temple is gripped with the spring hinge alignment tool. The tool hides all of the temple except the end of the temple. The "wrench" on the left extends the spring by pulling the barrel outward. Now the "tooth" slips into the notch in the hinge casing to hold the barrel in the extended position.

practitioners develop their own system of organizing the numerous small parts used in frame repairs. Others buy a preorganized system that already contains the most commonly needed parts, such as the one shown in Figure 10.24, and replenish the parts as necessary.

Titanium Screws

Because titanium is so strong, the threads on a titanium screw do not give. So if a titanium screw enters the barrels at even a slight angle, it will bind. If this happens, do not force the screw. Just back the screw out and start over. If it continues to bind after several attempts, put a drop of cutting oil into the barrel. (In the absence of cutting oil, which works best, use household oil such as 3-in-1.)[2]

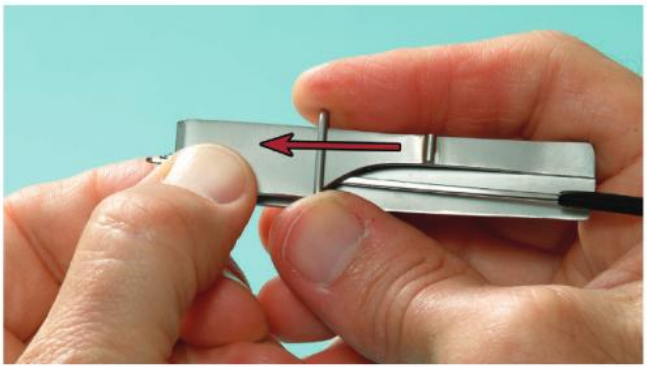

Figure 10.17 While squeezing the spring hinge alignment tool to keep the barrel extended, slip the slide forward so that the alignment tool locks in position and will securely hold the spring temple in the extended position.

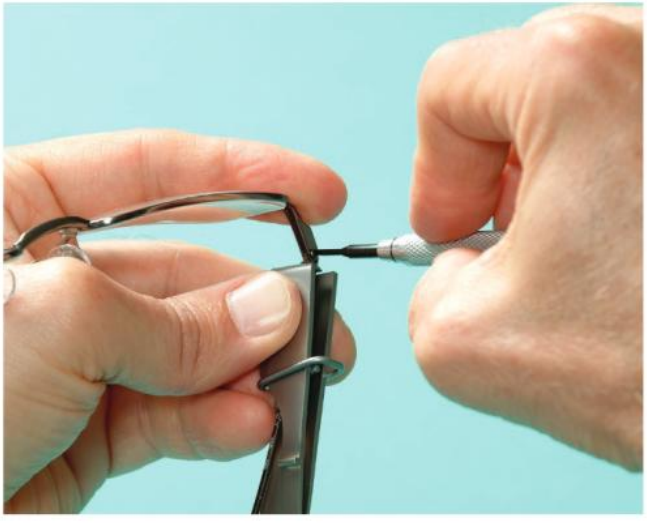

Figure 10.18 Now the temple will fit into the frame front, and all the barrels will line up. The screw should now go in as if the frame had a normal temple barrel configuration.

Figure 10.19 Here are the contents of the Hilco Spring Hinge Tool Kit. The kit works well and consists of a spring hinge lever, a hinge locking clamp, locking tweezers, and three pins. (From https://www.hilcovision.com/f/hilco-spring-hinge-tool-kit. Used with permission.)

Figure 10.20 Compressing the barrels together somewhat to help tighten up a loose temple is best done with pliers whose jaws are parallel when open. In this instance, hollow snipe-nosed pliers are being used. (Use caution. It is easy to overcorrect, squashing the barrels together too much.)

TABLE 10.1 Common Replacement Screw Diameter Sizes for Spectacle Frames

Type of Screws	Most Common Replacement Screw Size
Screws for regular spectacle frames, including both hinges and barrel-closing screws	1.4 mm
Screws for quality sunglass frames	1.6 mm
Screws for cheap, over-the-counter sunglasses	1.8 mm
Screws for nose pads	1.0 mm (If this will not fit, a 1.1-mm or 0.8-mm diameter will.)
Screws for spectacle frame trim	1.2 mm, 1.4 mm (sometimes 2.0 mm) (lengths from 2.9 mm–3.6 mm)

Data obtained from Woyton R. (undated). How can I find a replacement screw quickly when a customer comes in with a frame that needs one?" Hilco, Plainville, Mass.

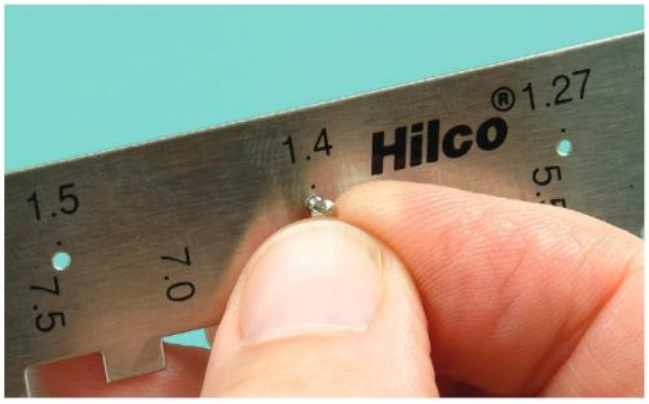

Figure 10.21 To find the diameter of the screw, slip the screw through each hole until a match is found. Incidentally, this 1.4 mm diameter is the most commonly used diameter for optical screws.

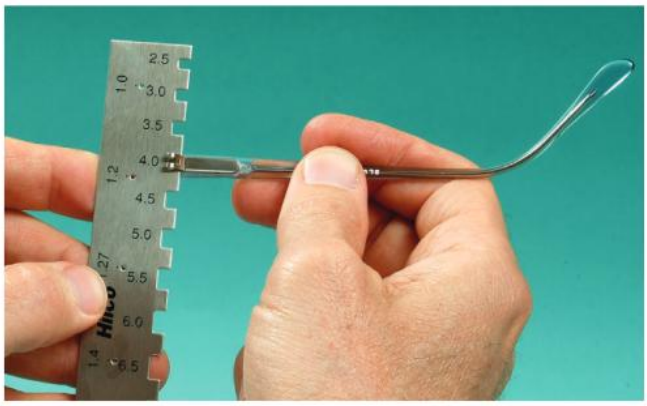

Figure 10.22 To find the screw length for a missing screw, measure the depth of the barrels and compensate an additional amount for the screw head. (Note: In other areas of industry, the head of the screw may not be included in its length.)

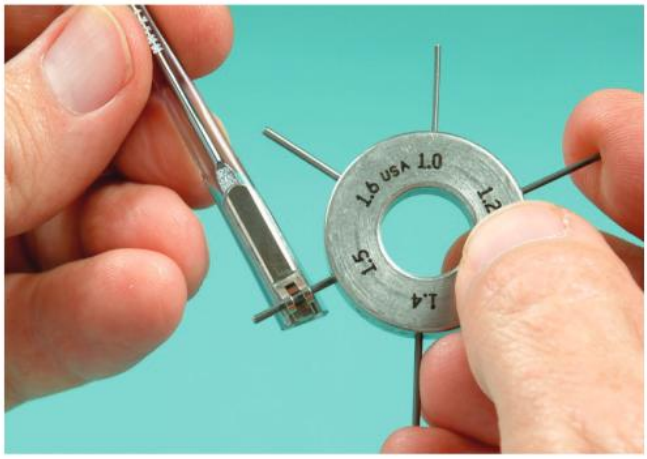

Figure 10.23 To find the diameter of a missing screw, slide the different sized spokes of the hole gauge through the barrels until the correct fit is found.

Broken and Stuck Screws

Sometimes a screw will not come out or breaks off in the barrels of the frame. Suggestions on how these problems may be corrected are outlined here and summarized in Box 10.2.

Removing Stuck Screws

If the entire screw is still in place but cannot be turned with a screwdriver, either the screw may have corroded in the barrel, or the screw slot may have been destroyed.

If corrosion is the problem, the screw can be loosened by immersing the affected area in an *ultrasonic cleaner* (Figure 10.25) or by treating it with a *penetrating oil* (Figure 10.26). (Note: If an ultrasonic cleaner is used and the lens is antireflection (AR) coated, either keep the lens out of the water or remove the lens before immersing it. Otherwise the AR coating can be damaged. Damage to the coating may not show up immediately.)

Another very effective but underutilized method is to heat the hinge in a frame warmer or by running hot water over it—if the water is hot enough. Then press a small candle, such as those used on birthday cakes, or a bit of paraffin onto the heated metal. The wax melts at 99 to 145°F (37 to 69°C) and will be drawn into the hinge barrels. Again use caution as exposing

Figure 10.24 Much searching time will be saved if an organized system for storing small frame parts is in place. This is a commercially available example of a stackable system that can be expanded as needed.

Figure 10.25 Ultrasonic cleaners will loosen frame screws while the frame is being cleaned. This can be used to advantage in loosening an especially stubborn screw. Keep in mind, however, that an ultrasonic unit may damage coated lenses or dislodge parts that are glued into the frame, such as rhinestones.

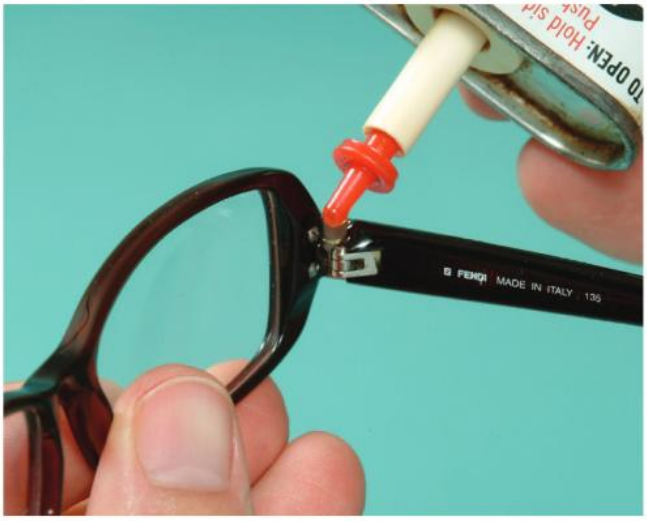

Figure 10.26 Penetrating oil, such as "Liquid Wrench" automotive penetrating oil, helps cut corrosion and loosen stuck screws.

BOX 10.2 How to Remove Stuck or Broken-Off Screws

To Remove a Stuck Screw:

1. Immerse in an ultrasonic unit.
2. Use penetrating oil, paraffin, or candle wax.
3. Place screwdriver in slot and lightly tap the screwdriver with a hammer.
4. Use a soldering iron or Hot Fingers unit.
5. Deepen the slot or cut a new slot at right angles to the old slot.
6. Drive the screw out.
   a. Use press-out, punch-out, or shoot-out type of punch pliers or
   b. Use a Bull's-Eye Screw Extractor™ or
   c. Use a pointed tool, an optician's hammer, and anvil.
7. Drill the screw out.
   a. Rethread with tap or
   b. Use a self-tapping replacement screw or
   c. Use a screw with a hex nut.
8. Replace the part.

To Remove a Broken-off Screw:

1. Use a screw extractor.
2. Slot the tip of the screw and attempt to screw it out from the bottom.
3. Drive the screw out.
   a. Use press-out, punch-out, or shoot-out type of punch pliers or
   b. Use a Bull's-Eye Screw Extractor™ or
   c. Use a pointed tool and anvil.
4. Drill the screw out.
   a. Rethread with tap or
   b. Use a self-tapping replacement screw or
   c. Use a screw with a hex nut.
5. Replace the part.

AR lenses to high heat may cause crazing of the AR coating.[1] When using a frame warmer, cover the lens with a lab towel.

Some dispensers remove frozen screws by supporting the tip of the screw on the edge of a small anvil or vise. After placing an optical screwdriver in the screw slot, the *screwdriver is gently tapped with an optician's hammer* once or twice, breaking corrosion or adhesive. (This method may require three hands.)

One idea for removing screws that have been previously bonded in the barrels with an adhesive is to *use a soldering iron set on low.*[3] The iron is held on the tip of the screw for 10 to 20 seconds until the hardened adhesive melts, allowing the screw to be removed normally. (Caution: Do not use this method on plastic frames.)

The Hot Fingers II™ unit works just as well as a soldering iron, if not better. (From here on, the terms *Hot Fingers II*™ and *Hot Fingers* will be used interchangeably. Hot Fingers II™ is the most recent model at the time of this writing.) Grasp the top and bottom of the screw with the Hot Finger tips (Figure 10.27). Heat the screw for 10 to 15 seconds. The metal expands when heated and contracts as it cools, helping to break

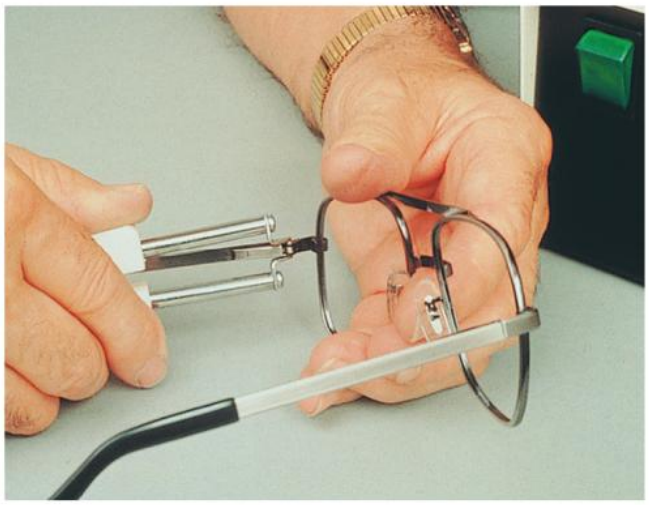

Figure 10.27 A Hot Fingers unit grasping the top and bottom of a previously sealed screw will often allow the screw to be removed normally. (Courtesy Hilco, Plainville, Mass.)

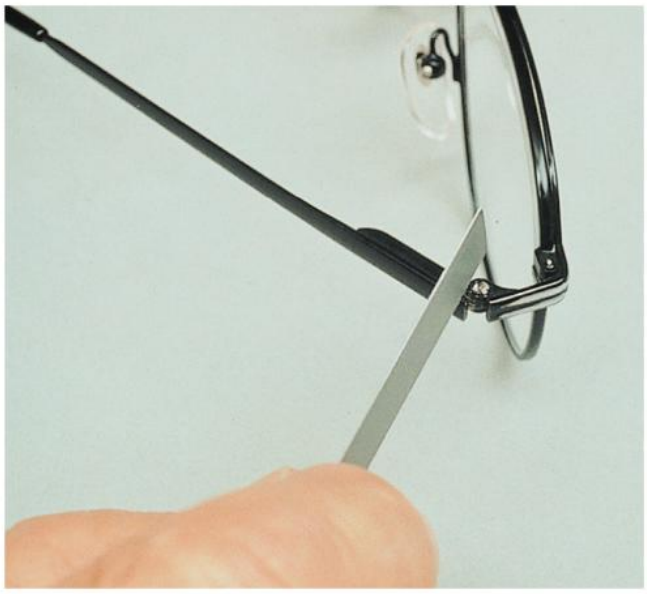

Figure 10.28 When the slot in the head of a screw has been destroyed, a new one can be created using a thin file known as a slotting or ribbon file. (It is sometimes possible to slot the tip of a broken screw as well. This allows a screwdriver to be used to turn the remaining part of the screw out of the bottom of the hinge.) (Courtesy Hilco, Plainville, Mass.)

the screw loose. The high heat also burns away any remaining adhesive. (Caution: Do not use this method on a plastic frame.)

To make both the soldering iron and Hot Fingers work even better, as soon as the screw area has been heated, quickly put a drop of oil on the screw. The heat thins the oil, and the oil is drawn between the threads, dissolving corrosion and lubricating the interface.[4] If neither a soldering iron nor a Hot Fingers unit is available, even heating the screw area with a frame warmer and then applying oil may help.

If the slot of the screw has been worn away, use a *flat slotting file to restore and deepen the slot* so the blade of the screwdriver can again turn the screw (Figure 10.28). If the slot is widened and damaged, try filing a new slot in the screw head. The new slot should be at right angles to the original slot.

If the screw is so corroded that it cannot be loosened and removed by any of the previous methods, it can be punched out. This is done with *a small hand pliers,* variously called *punch-out, knock-out,* or *shoot-out* pliers, that will punch out broken and stripped screws. (The pin in the pliers is replaceable.)

It is also possible to *drill the screw out.* This is described in the following section.

Removing Broken Screws

Replacing a broken-off screw is a tedious and time-consuming task. The most common cause for a screw to break off is overtightening by eyeglass wearers who think that a tighter screw will stop the frames from sliding down their nose. This is an incorrect assumption. When the first tightening doesn't resolve the problem, subsequent attempts shear off the screw, leaving the lower portion tightly wedged in the threaded barrel of the hinge.[1] The head can easily be removed if the slot is still usable, or it may fall out by itself. The other part of the screw remains stuck in the barrels.

The best tool for this job is a *screw extractor* (Figure 10.29). This device resembles a screwdriver but has a barbed end that digs into the stem of the screw and turns it. The extractor comes in a variety of sizes to suit the variations in screw diameters. It should be noted that first using the "birthday candle procedure" (see above under *Removing Stuck Screws*) will make removing the lower part of the screw much easier.

Figure 10.29 In a set of screw extractors, each extractor insert has two tips of different sizes. The extractor tip may be reversed in the same manner as with a two-ended screwdriver blade.

To use a screw extractor, attack the screw from the bottom (Figure 10.30). Apply hard downward pressure. If the broken-off portion remaining in the barrels is long enough, turn the screw clockwise. This will drive the screw out through the top barrel. If the broken-off portion is not long enough to go back out the top, turn the screw counterclockwise to bring it out of the bottom. It is often easier to bring the

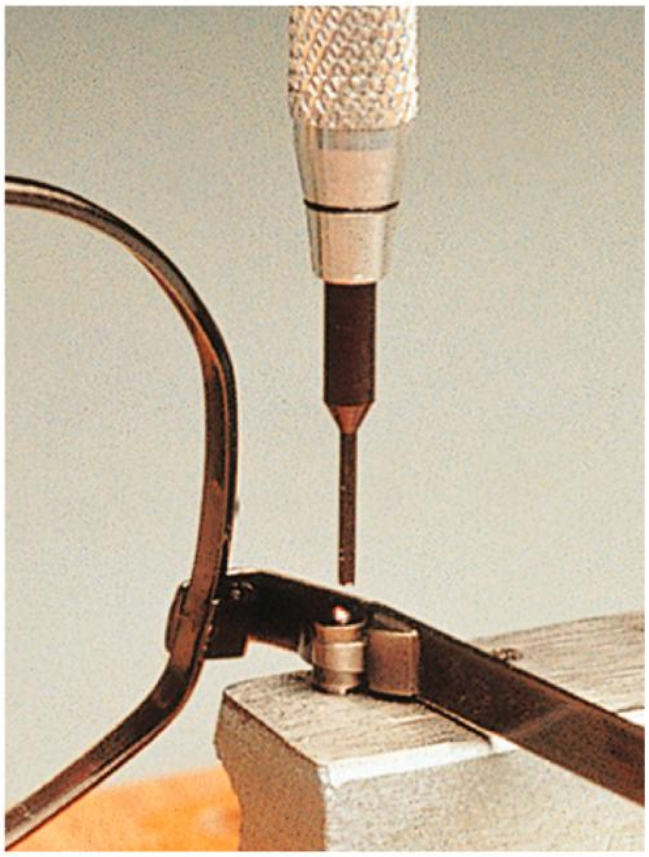

Figure 10.30 A screw extractor is used to gouge and grasp the tip of a broken off screw so that it may be turned. (Courtesy Hilco, Plainville, Mass.)

screw out from the bottom. Hint: The screw extractor tip can be removed from the handle and mounted in a Dremel tool having a standard Jacob's chuck. The extractor mounted in the chuck of the drill is shown in Figure 10.31.

If none of these methods work, it may be feasible to *drive out* the remaining portion of the screw. There is a device called the Bull's-Eye Screw Extractor (Figure 10.32). This device drives the screw out with a large amount of controlled pressure and can be helpful in removing the screw without having to drill it out. It does destroy the threads and will require a new screw as described in the section below giving procedures for drilling out screws.

Drilling a Screw Out

If all else fails, *drill out* the screw or its remaining portion (Figure 10.33). Use a drill bit slightly smaller than the diameter of the screw. Most screws in hinges and closing barrels are 1.4 mm in diameter. The drill size most commonly used for these screws is a 0.0430 (No. 57) bit. (When purchasing drill bits to drill metal, keep in mind that carbide bits last significantly longer than standard bits.)

Drill from the *bottom* of the screw. (The lower portion of the barrel is the threaded portion.) The conventional way of drilling starts by filing the screw flush with the barrel. Make a punch mark in the center of the screw to act as a guide in drilling. Center the drill carefully on the screw so as not to drill away the metal of the barrel surrounding the screw. Drill the screw out slowly, drilling and pausing to keep from overheating and ruining the drill bit. Always use a cutting or a household oil as a lubricant/coolant when drilling.

There is a drilling guide made especially for the purpose of keeping the drill bit on course so that it drills just the screw and not the hinge next to the screw. This is called the *Bull's-Eye Screw Drilling Guide.* The guide is clamped to the barrels with the bottom jaw of the guide over the

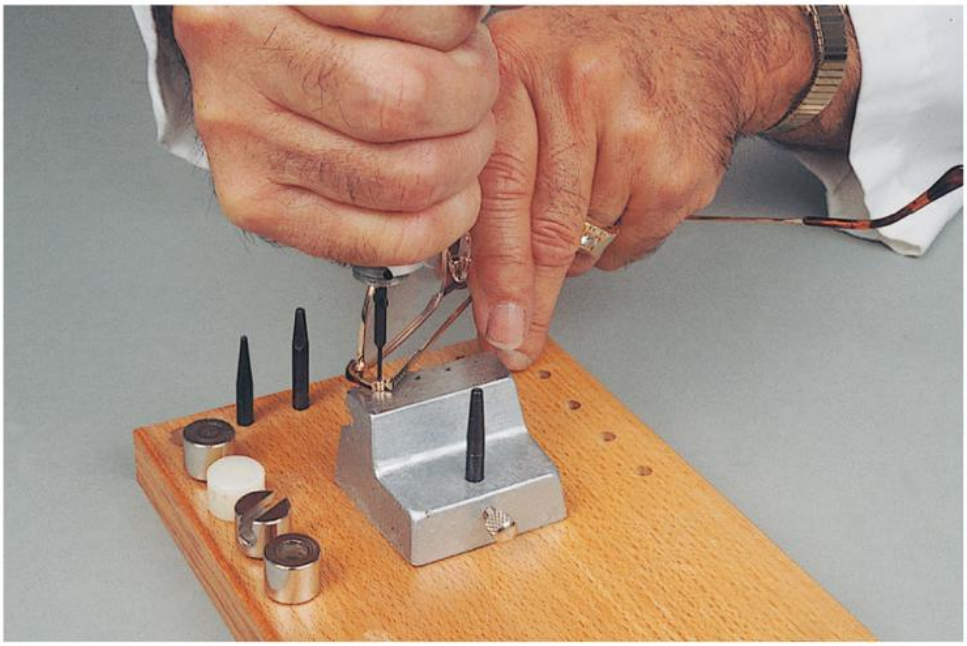

Figure 10.31 Mounting a screw extractor blade in a drill will allow extra torque to be applied when trying to remove a broken off screw. (Courtesy Hilco, Plainville, Mass.)

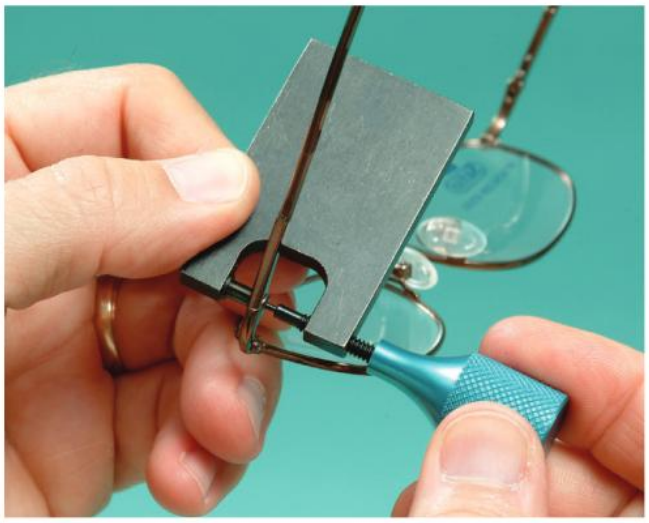

Figure 10.32 This simple device will place a lot of pressure on a broken off screw and accomplish the same thing that a regular screwdriver-like screw extractor may not be able to do.

Figure 10.33 A hanging motor drill is used to drill out a broken screw. The frame is being braced against an optician's anvil.

head of the screw (if the head is still there). After clamped in place, put a drop or two of oil into the top of the guide. Use a 0.0430 (No. 57) drill bit. The drill bit fits into the top of the drill guide as shown in Figure 10.34 and drills the screw out by drilling from the bottom of the screw.

The threads are destroyed whenever a drill bit or punch plier is used to drive out a screw. Use a tap to restore the threads (Figures 10.35 and 10.36). The tap can be either regular or oversized, depending on the hole

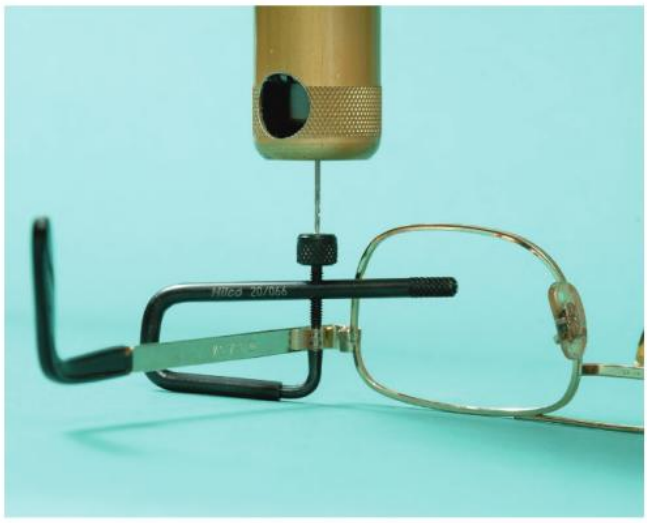

Figure 10.34 The Bull's-Eye Screw Drilling Guide is clamped to the screw. The drill is guided exactly onto the screw by going through a hole in the drilling guide.

Figure 10.35 A tap is a screw threader. It is held in a chuck with a handle. Threaders of varying size may be mounted in the chuck. The same handle can be used to mount a small drill bit for hand drilling plastic.

Figure 10.36 Using the tap to restore the threading involves nothing more than turning the tap clockwise into the barrels.

drilled. A standard screw can be reapplied if a regular tap can be used, but a special oversized screw must be used if an oversized tap is used.

When a tap cannot be used to restore the threads or is not desired, here are two alternatives:

1. *Use a self-tapping screw.* (This is explained in more detail in the next section and is the easiest alternative.)

2. *Use a longer bolt-like screw, often referred to as a glass screw, in combination with a hex nut* on the end to hold it tight (Figure 10.37). (Glass screws are, of course, not made of glass. They were originally used to mount a lens in a rimless mounting. Because the screw went through a glass lens, it was, and still is, called a "glass" screw.)

Glass screws are longer than temple screws. While tightening such a screw with a screwdriver, hold the hex nut with a hex wrench. Clip off the portion of the screw that protrudes beyond the hex nut, and file the end of the screw smooth to the surface of the nut. Because the bolt is usually visible after the repair, this is not a very attractive option.

Self-Tapping Screws

Self-tapping screws offer a simple alternative to rethreading (Figure 10.38). In most cases, they are superior to using glass screws with hex nuts.

Self-threading screws are longer than common screws. After being screwed into place, any excess length extending beyond the end of the barrel should be removed. Self-tapping screws are not cut off with cutting pliers but are snapped off using regular pliers, such as flat-round or needle-nose pliers.

When replacing screws with an oversized or a large self-tapping screw, make sure the screw freely passes through all the upper barrels that are not usually threaded. If the self-tapping screw is too large, it can break off before it is screwed in all the way, forcing the dispenser to start the process from the beginning. If the screw is too big to pass through the upper barrels, it is possible to enlarge the holes with either a drill bit or a rat tail file.

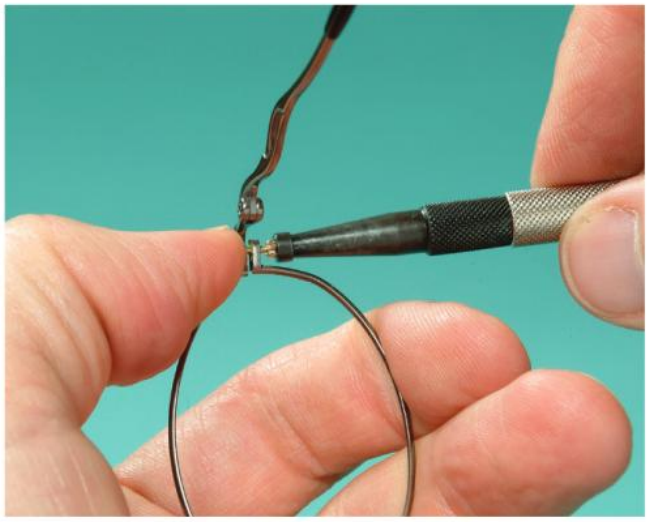

Figure 10.37 A "glass" screw and hex nut will serve when rethreading is no longer feasible. It is not always an attractive option. Look at the construction of the frame to see whether the nut should be at the top or bottom. The position that conceals the nut best is the preferred choice.

Figure 10.38 A self-tapping screw cuts its own threading. After the screw is fully in place, the excess is broken off with pliers. Do not attempt to use cutting pliers to shorten the screw. (Courtesy Hilco, Plainville, Mass.)

Replacing Rimless Screws

Sometimes, a screw that holds the lens in place in a rimless mounting will break, loosen, or have to be replaced. There are a large variety of mounting methods for rimless eyewear, making it difficult to describe repairs on every conceivable type. However, when lenses are held in place with screws, there are three basic types of assemblies. Each of these assemblies has more than just a screw with a nut. There is a combination of bushings and washers that protect the lens surfaces and remove some of the stress from the screw and nut.

Here are the basic components commonly used in the rimless assembly:

- *A screw*—The screw must be long enough to go through the mounting and full thickness of the lens. The thickness of the lens varies, so after assembly, the screw is cut off flush with the nut and filed smooth.
- *A nut*—The nut used can be either a hex nut or a star nut. The hex nut is screwed onto the screw with a nut driver (hex wrench); the star nut requires a star nut driver.
- *Washers*—There are both nylon and metal washers used. The nylon washer goes up against the lens surface and cushions the lens. The metal washer is the last thing between the nut and the rest of the assembly. The metal washer stabilizes the stress around the holes and acts as a barrier between the nut and the softer nylon washer or bushing surface.
- *Bushings*—Bushings are small, hollow cylinders that fit into the hole in the lens. The screw passes through the bushing instead of directly through the lens and cushions the lens. "Top hat" bushings are commonly used for rimless assemblies. These have a "rim" on the bushing that both holds the bushing in place near the surface of the lens and works like a nylon washer. Top hat bushings are the type of bushings commonly used for rimless mountings.

Figure 10.39 shows how three common rimless screw assemblies are put together using these components. Note: Even if the existing assembly on the wearer's old frame was put together with only a screw and a nut, when making a change, add a nylon washer between the lens and the nut. Better still, use a nylon bushing to protect the lens from the screw.

Rimless Compression Mountings

Rimless eyeglasses that use compression-type mountings are now a more common type made popular by the Silhouette frame company. The lens normally has two adjacent drilled holes on each side of the lens—one set for the bridge and the other for the temple (Figure 10.40). The frame bridge and temple have posts that slip through mounting sleeves. The mounting sleeve (Figure 10.41) comes in contact with the inside of the drilled lens holes, padding the posts and reducing stress on the lens.

Repairing a Damaged Compression Mounting

When a rimless compression mounting has become loose or needs repairing, here are the steps for repairing it.

1. Before attempting to put a rimless compression mounting back together, check the following:
   - Are the drilled lens holes acceptable? In other words, are there stress cracks in the lens around the mounting? Is the lens broken between the two holes or between a lens hole and the edge of the lens? If so, the lens should be replaced. Your repair may result in a later failure, and you will be blamed.
   - Are the posts on the bridge and temples of the rimless mounting damaged or missing? If so, the frame will need to be replaced as it is not repairable.

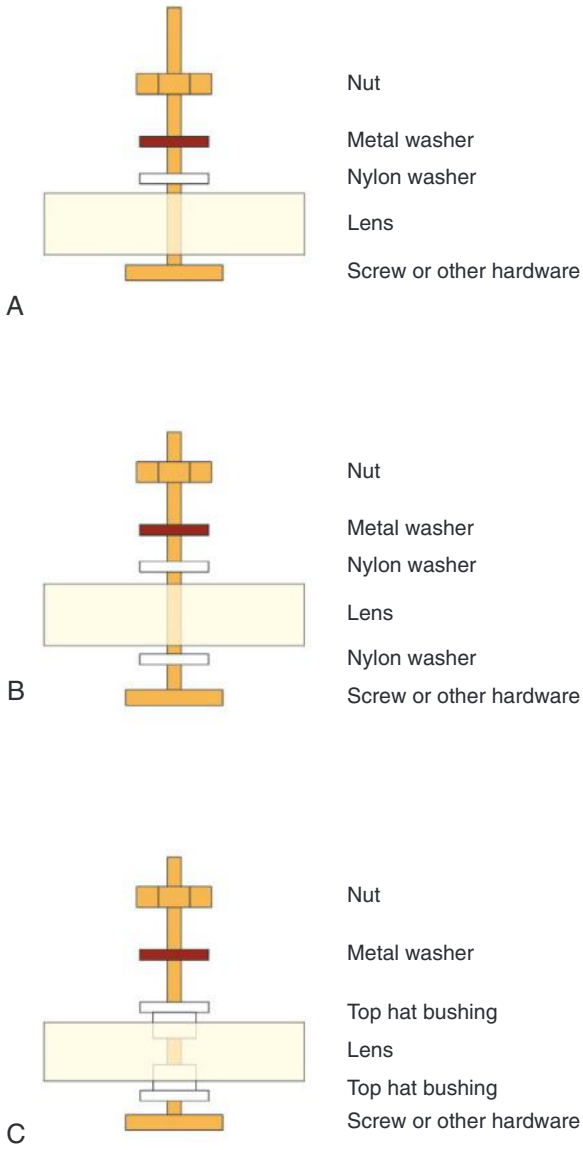

Figure 10.39 Here are three basic rimless assembly designs that might be used. Which one is used will depend upon the frame design. Some designs use an entirely different method of securing the lens in place. **A,** A simple rimless screw assembly consists of a regular or decorative screw, a nylon washer on the back to protect the lens, a metal washer to stabilize the stress areas, and the nut. The nut may be a hex or a star nut. **B,** A common assembly cushioning both the front and back of the lens with nylon washers. **C,** Top hat bushings replace nylon washers, protect the hole in the lens, and add stability to the assembly.

2. Clean off any plastic material remaining on the temple or bridge mounting posts or prongs. This is done using Compression Sleeve Trimming Pliers (Figure 10.42). These are not cutting pliers and are not to be used to cut metal! The edges are razor sharp to cleanly trim compression sleeves.
3. Coming from the back of the lens, press the replacement compression sleeve through the existing mounting holes in the lens. Trim the sleeves from the front using the compression sleeve trimming pliers shown in Figure 10.42. Leave about 1 mm of length protruding from the lens surface. The trimming plier surfaces are highly polished to prevent lens scratching when cutting the plastic compression bushing off of a lens.

To make insertion of the posts easier, it is possible to first flare out the protruding ends of the sleeves. Some recommend using a push pin. (A push pin is a like a thumb tack used to hold paper on a cork or bulletin board. The difference is that it has a plastic head for easy removal from the board.)

4. Press the temple or bridge piece posts into the sleeves by hand initially. Then use Rimless Compression Pliers (Figure 10.43) to completely push the posts of the mounting into the sleeves. (Come in from the top of the frame with the pliers, since the drilled holes are closer to the top. There is less lens to get in the way when coming from the top.) When the assembly is pressed together using Rimless Compression Pliers, notice that one side of the jaw rocks. That jaw goes on the back surface of the lens so that it will conform to the back curve of the lens.
5. After repairing the faulty compression mounting, check the remaining mountings. If they feel loose, use the Rimless Compression Pliers to tighten them so the mounting doesn't wiggle loosely. If a compression mounting does not tighten up, it should be replaced.

Replacing an Intact Compression Mounting

As stated previously, if a compression mounting is not broken but does not tighten up, it should be replaced. Here are the steps for replacing an intact compression mounting:

1. To replace an intact mounting, snip off the compression mounting from the back using the compression sleeve trimming pliers (Figure 10.42). They are highly polished to keep them from scratching the lens surface and have a somewhat convex cutting head to conform to the concave back surface of the lens.
2. Now use the Compression Sleeve Removal Tweezers (Figure 10.44) to press the metal pins of the rimless mounting out from the back of the lens.
3. If one has trouble removing the old compression sleeve assembly from the lens, there are compression mounting hardware removal pliers (Figure 10.45) to first cut the compression sleeve assembly apart between the two prongs. Then the sleeves may be cut off flush from the back. These pliers have a small head that will fit between the pins. The head is highly polished so that it does not mark the lens.

Once the temple or bridge is removed from the lens, the remaining procedures are the same as the repair explanation in the previous section.

NOSE PAD REPLACEMENTS

There are many different types of nose pad assemblies. The push-on and screw-on type nose pad assemblies are the most dominant. Eyecare professionals should carry both versions. These are described first. Some of the more uncommon and antique styles are mentioned next. These include clip-on, twist-on, Zeiss bayonet, split-clamp, stirrup, and rivet types.

Push-On

The *push-on pad* is one of the easiest pads to remove and replace. It has a small I-beam-like shape that snaps into an indented box on the pad arm (Figure 10.46). The part of the pad that slips into the box may be either metal or hard plastic.

Although a push-on pad can be removed without the aid of tools, it is possible to use a small device called a *pad popper*. This device is slipped between the pad and the pad arm attachment as shown in Figures 10.47 and 10.48.

There are pliers specifically designed to aid in attaching a push-on pad to the pad arm. Known as *Push-On Pad Pliers,* they have a curved

Figure 10.40 Compression mountings normally have two adjacent drilled holes—one set of two on the nasal side for the bridge and one set on the temporal side for attaching the temple. (From https://www.silhouette.com/us/us/optical-eyewear/mosaic/5468/6053. Used by permission.)

Figure 10.41 Compression mounting sleeves are between the mounting posts of a rimless compression mounting and the inside of the drilled lens holes. Replacement sleeves are available in both single and double form. They also come in a variety of diameters to match drilled hole sizes. (Hilco Rimless Mounting Sleeves, From https://www.hilcovision.com/f/rimless-mounting-sleeves. Used by permission.)

Figure 10.42 Compression Sleeve Trimming Pliers have extremely sharp edges to cleanly cut plastic mounting sleeves. Using them on metal as cutting pliers will ruin the cutting edges. (From www.hilcovision.com/f/ergopro-compression-sleeve-trimming-pliers. Used by permission.)

Figure 10.43 One jaw of Rimless Compression Pliers is meant to rock so that it will conform to the angle of the back curve of the lens.

Figure 10.44 Compression Sleeve Removal Tweezers. The two posts on the tweezers press against the posts of the rimless mounting to squeeze the frame hardware out from the lens. (From https://www.hilcovision.com/f/compression-sleeve-removal-tweezers. Used by permission.)

nylon jaw on one side that cradles the pad face and a flat, metal jaw on the other side to hold the pad arm in place.

If a push-on pad will not stay in the box securely, use a pair of pliers to squeeze and narrow the horizontal dimension of the box slightly.

Screw-On

The *screw-on type* of attachment has a small post on the back of the pad with a horizontal hole in the post. The post slips into either a box-like

Figure 10.45 If needed, Compression Mount Hardware Removal Pliers may be used to cut the compression sleeve assembly apart between the two sleeves. (From https://www.hilcovision.com/f/ergopro-compression-mount-hardware-removal-pliers. Used by permission.)

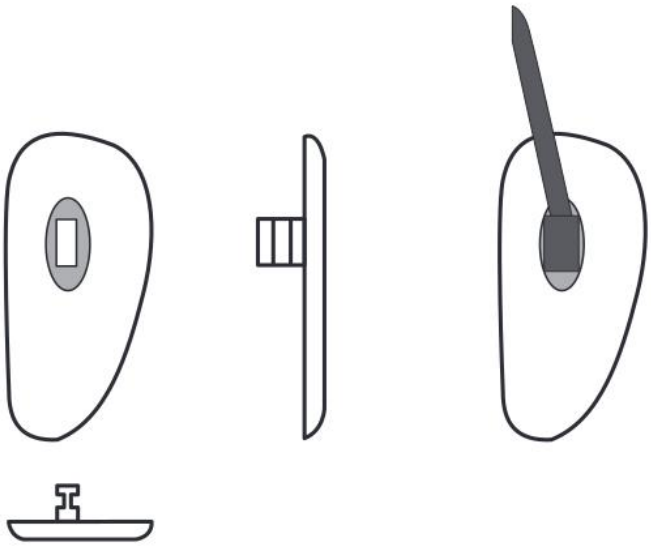

Figure 10.46 The *push-on* nose pad design slips into an indented box on the pad arm.

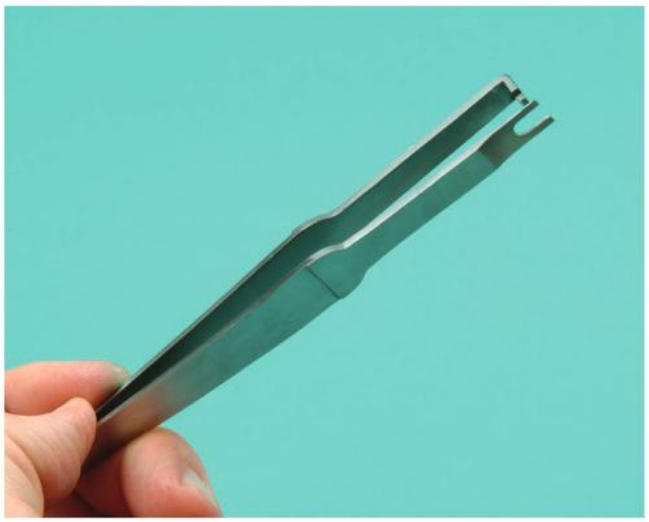

Figure 10.47 A pad popper is used to remove push-on pads without affecting the pad arm alignment.

assembly or a rounded piece on the pad arm (Figure 10.49). A screw is threaded from one side of the box to the other, passing through the hole in the pad post. The screw is so small that a special screwdriver is usually required.

The greatest problem with the screw-on pad design is having a properly fitting replacement screw available. If someone has the unmounted pad but not the screw, it may be difficult to find a suitable replacement screw. The most common nose pad screw diameter is 1.0 mm. If this screw is too small, a 1.1-mm diameter screw should do the job. Since most companies list screw diameters, getting to know the most common sizes can be helpful in finding replacement screws.

As a last resort, if no replacement screw is available, the nose pad can be temporarily "tied" on using the same type of nylon line as is used to "string mount" lenses. The excess line is cut off using cutting pliers or a razor blade.

Logic®

There is a specialty replacement nose pad with an insert that fits both push-on and screw-on types of pad arms. This pad, called the Logic® pad by Hilco, comes in round or oval shapes and is symmetrical, making left and right pads interchangeable. This reduces the need to keep as many pads in inventory (Figure 10.50).

Pad Sizes

Pads are manufactured in various sizes. Sizes can be changed to match the nasal area available or to increase the bearing area when the pressure from the weight of the frame on the nose is too concentrated. Oval pads measuring 11, 13, 15, 17, and 20 mm in their vertical axes and round pads measuring 9 and 11 mm are the most common sizes, although other sizes are available.

Types of Pad Materials

Replacement pads are available in several different materials, having varying degrees of flexibility. Here are the three most common materials:

- ***Acetate pads***— Pads made from cellulose acetate material (sometimes just called *acetate*) are hard and do not flex. Cellulose acetate is the same material used for a great many plastic frames.
- ***Vinyl pads***— There are also pads made from a soft, vinyl material. Although these pads are flexible, they do not "grab" the nose but will slide on the nose more easily than a silicone pad.
- ***Silicone pads***— Silicone pads do not slide down the nose as easily, even when perspiration or skin oil are present. This is not to say that the pads do not slide at all, but rather they slide much less. Although this is advantageous, it may irritate some people's skin because they may feel a pulling sensation on the skin. If an individual complains that the nose pads seem to pull and irritate, it may be helpful to switch to an acetate or vinyl pad. (The wearer should, of course, be made aware that the glasses will slide more easily. The solution is a trade-off.) Silicone pads come in varying flexibility. The softness or firmness of the pad does not depend on the basic material but rather on the mounting insert that is molded into the silicone pad. Soft silicone pads have a small metal mounting inside the pad, whereas firm silicone pads have a metal insert imbedded in a nylon core within the pad. Flex silicone pads do not have a metal insert but instead have a thin nylon core.

Hypoallergenic Nose Pad Materials

There are wearers who are sensitive to standard nose pad materials. Here are some options that usually satisfy these wearers:

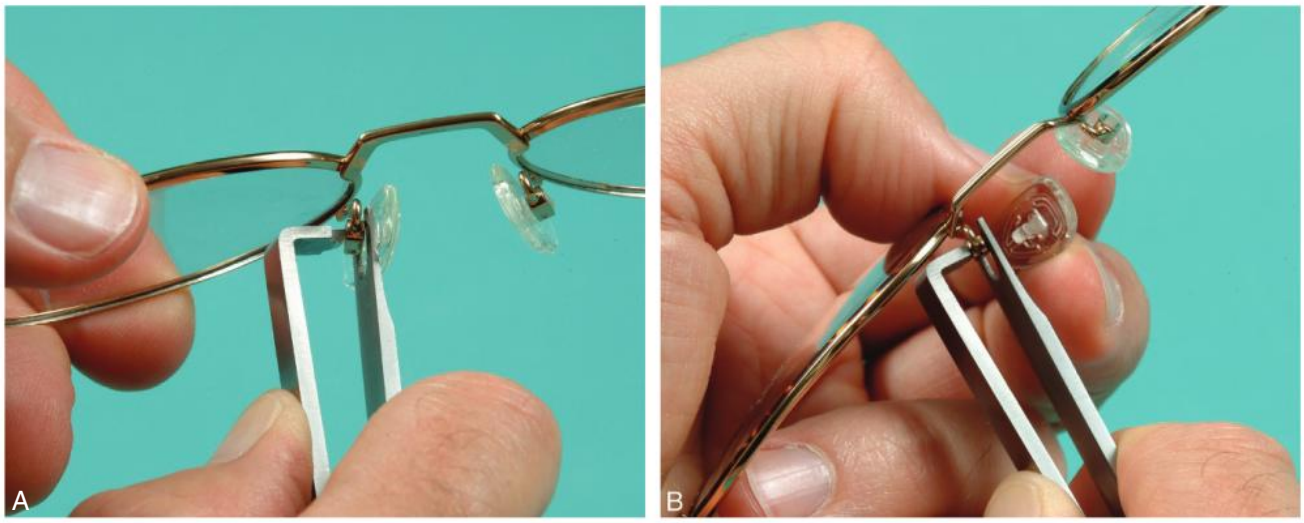

Figure 10.48 **A,** The thin edge is slipped between the pad and the pad arm. **B,** The back of the pad has been pressed out of the box on the pad arm.

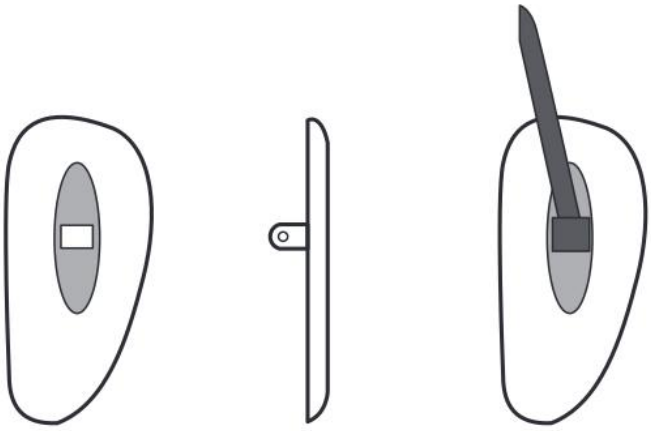

Figure 10.49 The *screw-on* pad design requires a small screw to secure it to the pad arm.

Figure 10.50 This Logic nose pad serves as a replacement for either the screw-on or the push-on type of nose pads.

- *Titanium pads*—Titanium is extremely well tolerated by those with skin allergies. These nose pads are made of 100% titanium.
- *Crystal pads*—There are pads made of crystal. These look more like regular nose pads and solve the problem of allergic reactions.

Replacing Adjustable Pads with Strap Bridges

A *strap bridge* is like two adjustable pads whose tops are linked together with a "strap." The strap is of the same material as the pads and is really an extension of them; the pads and strap are one unit

Figure 10.51 A *strap bridge* replaces two adjustable pads. It distributes frame weight over both the traditional nose pad areas and across the crest of the nose. The flexibility of the material allows both pads to still be adjusted separately.

(Figure 10.51). A strap bridge increases the pad bearing area to include the crest of the nose. Strap bridges are attached to the pad arms in the same manner as are adjustable pads. They are also adjusted to the fitting angles of the nose in the same manner as conventional nose pads. Since the whole piece is flexible, left and right halves adjust independently.

Replacing Lesser-Used Types of Nose Pads

As previously stated, the two most common types of nose pads are push-on and screw-on pads. The pad styles presented below are lesser-used styles or antique styles. Even antique styles are still available as replacement parts. When individuals bring in a frame they want restored to use for their prescription, pads may need to be replaced.

Clip-On

The *clip-on design,* also known as *B & L clamp style,* consists of two curled hooks on the pad that fit about an indented "waist" in the

bearing area of the pad arm (Figure 10.52). The hooks are passed about this waist and then clamped tight with pliers.

If a broken or corroded pad is to be removed, a special bifurcated tool can be used to separate the hooks to remove them. If this tool is not available, an ordinary optical screwdriver may be used to pry up the hooks by forcing the blade under them. Care should be taken not to clamp the hooks too tightly. Too tight of a clamp totally eliminates the play of the pads at their juncture with the pad arms.

Twist-On

One system that twists into place has employed a vertical metal stud that is attached to the pad. This *twist-on method* is sometimes referred to as the *A.O. twist system*. The shaft of the stud itself is indented with two slots that permit it to be inserted, with its long axis horizontal, into a horizontal slot in the pad arm.

When the pad is rotated to a vertical position, the ears on the stud overlap the sides of the slot in the pad arm, preventing the pad from falling off the pad arm (Figure 10.53).

Zeiss Bayonet

The *Zeiss bayonet style pad* slips onto a ridged pad arm (Figure 10.54). It is simple to remove and replace. Some, but not all, types of Zeiss bayonet pads are made so that they will turn around 180 degrees for attachment either "frontward or backward."

When the hole for the pad arm is not centered in reference to the front and back surfaces of the pad, switching the pads left-for-right and right-for-left will increase the distance between pad surfaces, either making the frame more suitable for a wider nose or causing the frame to sit lower on the face.

Split-Clamp

There is a pad with a back that consists of two clasp-like pieces of metal, much like the fastener on a large mailing envelope. These two pieces fit through the vertically elongated hole in the pad arm and are spread to hold the frame in place (Figure 10.55). It is sometimes called the *A.O. split-type* of attachment.

Stirrup

The *stirrup type* of mechanism consists of a miniature cylinder attached to the back of the pad. (It is similar to the post of the screw-on type pad.) Occasionally, the cylinder may have a square or oval cross section rather than a round one.

The pad arm ends in a stirrup-like structure that has the bottom of the "footrest" divided in two. The stirrup is spread apart, using a special tool, a screwdriver blade, or pliers. When half of each stirrup is astride the cylinder with the ends of the footrest facing the holes, the footrest is then compressed so that each end fits into the corresponding hole.

It is difficult to remove such pads since a special tool is required to spread the stirrup footrest once it has been compressed about a pad. It is

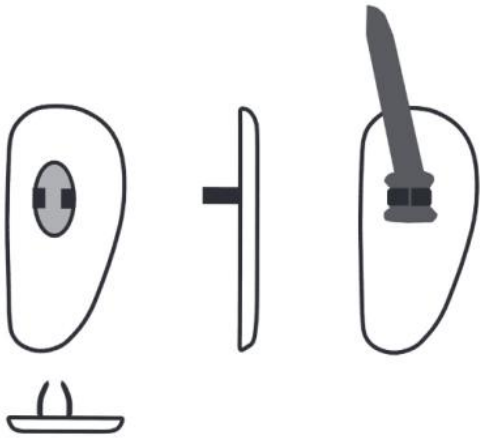

Figure 10.52 The clip-on pad design is also referred to as the *B & L clamp style*.

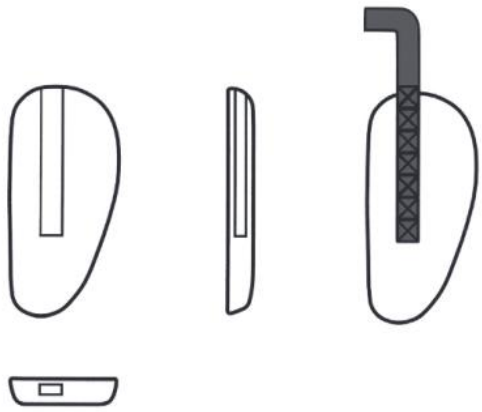

Figure 10.54 The *Zeiss bayonet* pad design is extremely easy to change and adds the possibility of changing vertex distance and pad separation without moving the basic position of the pad arms.

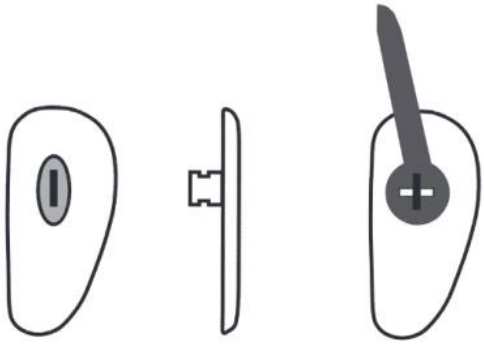

Figure 10.53 The twist-on pad design is sometimes called the *A.O. twist system*.

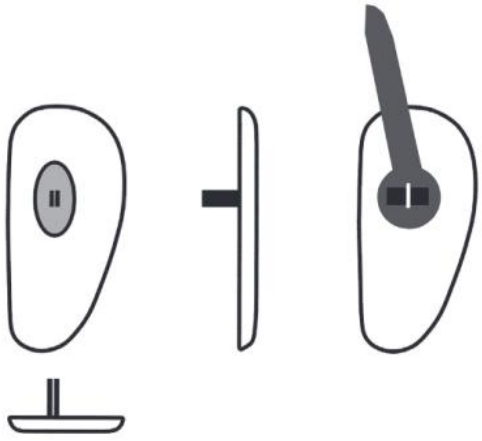

Figure 10.55 The split-clamp pad design is also referred to as the *A.O. split-type* of attachment.

possible to remove them using a screwdriver blade but with more difficulty.

Rivet Type

Some older types of pads are attached by means of a loosely fitting rivet-like system that allows rocking of the pads. It is a semipermanent arrangement and cannot be removed unless clipped off. If it becomes necessary to replace this type of pad, the replacement is a split-clamp design and works like the fastener on a large mailing envelope. The replacement pad clips are inserted through this rivet hole in the pad arm and then spread.

TEMPLE REPAIRS

Replacing Missing or Broken Temples

If a pair of glasses has an irreparably broken temple, it must be replaced. The first choice is to replace it with a new identical temple. Unfortunately, a new matching temple will not always be available. The frame style may have been discontinued, and it may be impossible to obtain a matching replacement.

Replacing with an Old Temple

Most dispensaries keep a selection of old temples that can be used for temporary replacement purposes. The most difficult task is to find a temple that both looks acceptable and has a hinge with a barrel configuration that matches the frame front. If no match is found, it may be feasible to modify the temple barrels. The result may be functional but less than ideal.

For example, suppose one barrel is a single thick barrel and slightly large for the other two matching barrels. In such a case, it may be possible to file either or both the top and bottom of the large, single barrel down so that it fits into the smaller space between the other two barrels.

Eyeglass frame temples come as either a right or a left. Sometimes a left temple is necessary and all that is available is a right temple. For some hinges, it is possible to mount the right temple on the left side or vice versa. If this is done, the bent-down portion will turn up instead of down. If the temple looks acceptable, heat the temple bend, and bend the earpiece down.

Replacing Plastic Earpiece Covers on Metal Temples

Most metal temples are made such that the end of the temple is plastic covered. This allows for greater comfort. If the plastic temple cover becomes damaged, it may be replaced. Plastic replacement temple tips come in a large variety of colors and shapes. They are also available in silicone material to help decrease slippage. The most popular core diameters are 1.4 mm and 1.6 mm.

To replace a temple tip,[5] heat the plastic end of the temple, straighten it out completely, and pull the plastic cover off.

Determine the size of the metal core by measuring or using actual-size diagrams provided by the manufacturer of the replacement tips. (One way to quickly find the diameter of the core wire is to use the same type of gauge used to measure screw diameters as discussed earlier in this chapter.) Match the shape and color of the tip as closely as possible.

Push the replacement tip onto the metal core. (If the core is round instead of rectangular, it is easier to use a back-and-forth twisting motion to get the replacement tip on the temple.) It may be necessary to heat the replacement tip.

The temple may now be rebent so that the bend is just posterior to the top of the ear as described in Chapter 9.

Adding Covers to Cable Temple Earpieces

Some people who need cable temples may be bothered because they find the cable uncomfortable or because they have an allergic reaction to the metal cable. An allergic response is usually caused by nickel content in the frame material. Signs of this reaction are a rash behind the ear and the cable turning green.

It is possible to cover the end of a cable temple with a plastic cover. Although covers for cable temples may be available in plastic, vinyl, and silicone materials, these covers may be more difficult to find. This is because "heat-shrink" tubing is generally the method of choice for this purpose.

Shrink tubing is a simple solution to covering the end of a cable. The inside diameter of a heat-shrink temple cover is larger than the diameter of the cable temple. To apply this tubing, do the following:

1. Determine the diameter size of the shrink tubing needed so it will slip over the end of the cable.
2. Measure how much length is needed. (Allow 10% over the measured length to allow for shrinkage.)
3. Cut a strip to length and slide the cover over the end of the cable temple (Figure 10.56, *A*).
4. Heat both the temple and cover with a hot air frame warmer at the hottest setting (see Figure 10.56, *B*) until the tubing shrinks to fit the temple snugly (see Figure 10.56, *C*).
5. Trim off any excess material.
6. Heat the trimmed area to smooth the edges.

Covering the Temples to Reduce Allergic Reactions

If a wearer has an allergic reaction to the temple along the side of the head, the frame may be sent out to a frame repair center to be entirely coated.

Figure 10.56 It is possible to cover the end of a cable temple with heat-shrink cable tip covers. Find the correct diameter, cut to length, and slip over the end of the cable temple, as shown in **A.** Heat using a frame warmer on the highest setting, as shown in **B.** Heat-shrink cable tips tighten up snugly, as seen on the temple shown in **C.** (Courtesy Hilco, Plainville, Mass.)

A second option is to use clear, ultrathin shrink tubing that places a thin, clear barrier over the temple. This is done by sliding the tubing over the temple and then heating both tubing and temple with a hot air frame warmer.

Lengthening and Shortening of Metal Temples

Metal temples usually come with bent-down portions that have a metal core covered with a plastic outer earpiece portion. These types of temples can be shortened or lengthened beyond what would be expected.

To lengthen—Sometimes the desired frame is not made with temples that are long enough for the wearer. Even if the bend is moved by heating and rebending, there is insufficient length for a suitable fit. If this is the case, there are two alternatives:

Figure 10.57 Resizing a metal temple using plastic temple tip sizers is no harder than simply replacing the plastic ends. All three of these temple ends will interchange to fit the same temple. (Courtesy Hilco, Plainville, Mass.)

1. The first alternative is to heat and straighten the temple. Then pull on the temple cover as if to remove it, but only let it slide off part of the way. For example, if the temple is too short by 5 mm, pull the temple cover so that it slides 5 mm out. Now rebend the temple so that it is of the proper size. This method does not provide as much support and makes the end of the temple weaker than it would be otherwise.
2. The second alternative is to replace the plastic temple ends. Optical suppliers have temple tip extenders that will allow adding 5 to 15 mm in length to the size of a metal temple just by changing the plastic temple ends (Figure 10.57).

To shorten—If the temple is too long (Figure 10.58, *A*) and cannot be made sufficiently short by moving the temple bend, the temple must be shortened. To shorten the temple, heat the temple end, straighten it (see Figure 10.58, *B*), and pull the plastic cover completely off. Clip off the end of the metal core (see Figure 10.58, *C*). (The amount clipped should equal the amount the temple must be shortened.) Slip the plastic cover back on; it will now go on farther than it did before, making the temple shorter (see Figure 10.58, *D*). Complete the adjustment by rebending the temple to the appropriate length.

Sometimes, it is necessary to file down a temple "shoulder" if the cover will not go on past the shoulder without splitting. (That part of the metal temple that is still flat, just before the temple narrows down to a small, round diameter, is called the *shoulder*.) If this is the case, file either or both the top and bottom of the shoulder (Figure 10.59). The shoulder must be thin enough to allow the temple cover to slide all the way up without splitting.

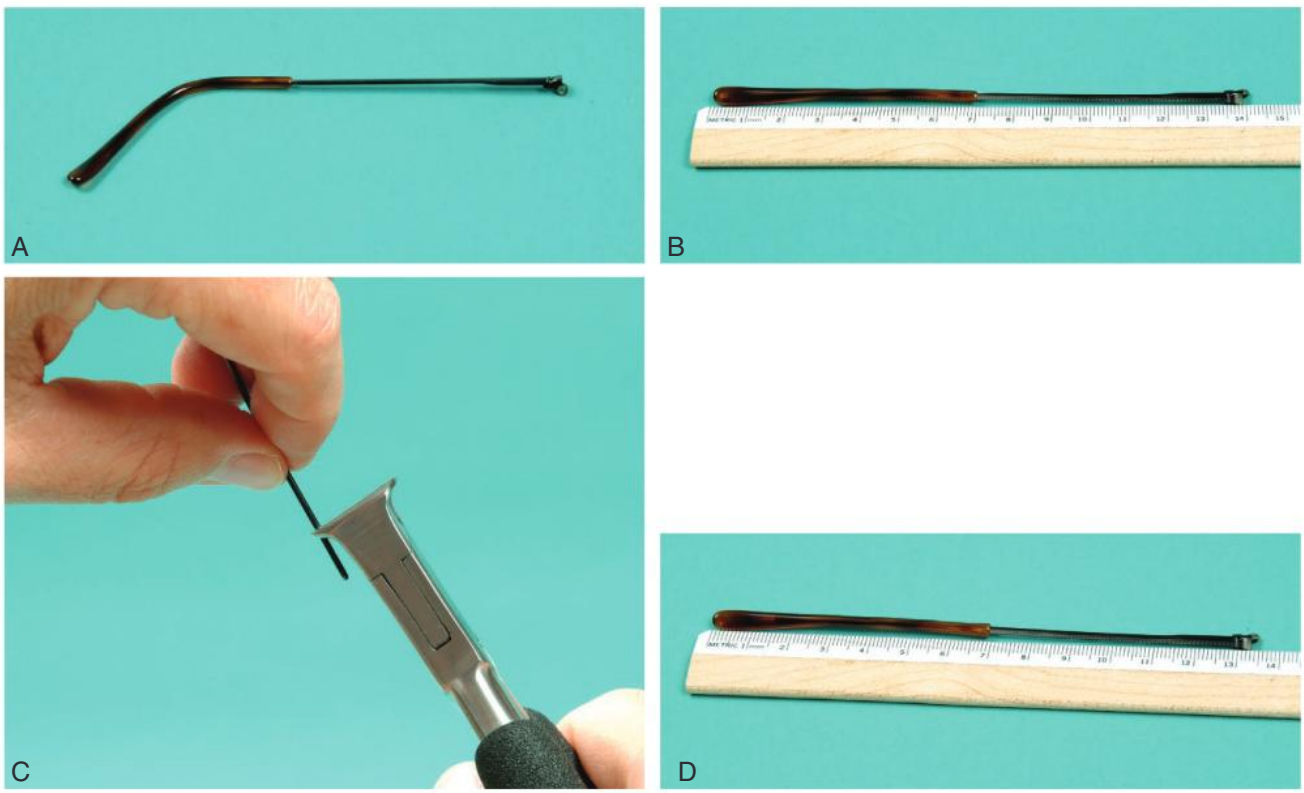

Figure 10.58 Sometimes just moving the location of the bend will not make a temple short enough without leaving an excessively long and unsightly bent-down portion. **A,** Metal temples with plastic temple ends, such as the one shown, can be shortened another way. **B,** To shorten this type of temple, the bend is straightened and the plastic cover pulled off. This temple has an overall length of 145 mm. **C,** Once the plastic cover is removed, the tip of the metal core is clipped. **D,** The temple cover is replaced and is measurably shorter.

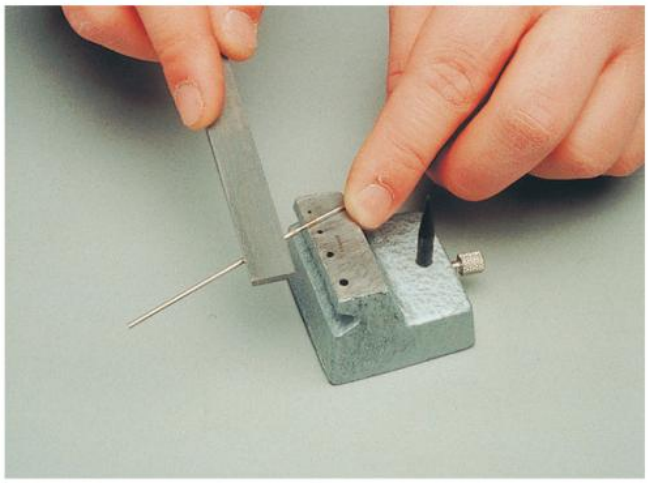

Figure 10.59 Some metal temples widen close to the location of the plastic end cover. The place where the temple widens is called the *shoulder*. If a temple has been clipped short and the plastic end cannot be put back on without splitting the plastic, the shoulder must be filed.

When the plastic cover is slipped back on, it will now go on farther than it did before, making the temple shorter.

Help in Making Temple Tip Changes Easier

There can be some challenges when changing temple tips. Here are some hints to make the job easier[6]:

- If the old, damaged temple cover will not come off just by heating and sliding it off, use pliers to crush the old plastic until it does come off.
- File any rough places off the metal core of the temple, making certain that the end is filed smooth and rounded.
- Before trying to slide the new temple cover on, heat up the metal core. Slide the temple tip on as far as it will go, and then heat the tip with the frame warmer until it will slide on the rest of the way.

Changing Cable Temple Lengths

Cable temples may be shortened by clipping and either lengthened or shortened by replacing the curled end.

Shortening Cable Temples

If it becomes necessary to shorten a cable temple that is too long, shortening is done by simply clipping off the excess portion of the cable with cutting pliers. The rolled metal cable must be sealed so it will not unravel. To seal the cable, touch the cut end with a soldering iron, apply a small amount of solder, and allow the solder to form a small ball at the end. (It may be desirable to combine this with a heat-shrink cable tip cover.)

Lengthening, Shortening, or Replacing Cable Temple Ends with Silicone Cable

Hilco makes a silicone replacement cable end that may be used to either lengthen or shorten a cable temple. The curled silicone does not have a metal core but rather one made of acetate. To replace the curled end, use the following sequence of steps:

1. Determine the desired overall temple length.
2. Determine what length of curled cable is to be replaced, and get the pair of replacement cable ends in the desired size and color.
3. Subtract the length of the temple to be replaced from the overall temple length.
4. Measure from the hinge center along the temple until the length determined in step 3 is reached. Mark the temple at this point.
5. Measure back an additional 8 mm, and mark the temple a second time. This is the cut-off point.
6. Cut the temple off at the second mark, and discard the cut-off portion.
7. Heat the replacement cable with a hot air frame warmer for 20 to 30 seconds.
8. Slide the replacement cable onto the core wire until the front of the replacement cable reaches the first mark measured.
9. Cool the whole temple in water to contract the replacement cable for a firm hold.

Example 10.1

A cable temple is too short. It is 160 mm long and needs to be 170 mm long. Replacement cable ends come in a variety of sizes. The appropriate length is the length that will allow a proper fit around the back of the ear (shown earlier in Figure 9.28, *A*) and end at a logical point of attachment to the straight portion of the temple. In this case, we will say that our replacement cable end length is 90 mm. To what length should the cable temple be cut to achieve the new length?

Solution

If the overall desired length is 170 mm, we subtract 90 from 170, which equals 80 mm (170 mm − 90 mm = 80 mm). This 80-mm length is measured back from the center of the hinge barrel and marked. Then an additional 8 mm is measured (at 88 mm) and also marked. The temple is cut at the second mark, and the 90-mm replacement part is attached.

Converting Standard Plastic Temples to Cable-Style Temples

The same replacement cable ends that were used for the procedure described previously can also be used to convert a standard plastic temple to a cable-style temple. The procedure is very similar to that of changing the length of a cable temple and replacing it with a silicone cable.

First, determine the desired overall cable temple length and the length of the curled replacement cable end that will fit correctly. Match size of the replacement cable end to the wearer's ear and the color of the replacement to the original plastic temple.

Subtract the length of the replacement cable end from the desired overall cable temple length. Measure from the center of the plastic temple hinge until that length is reached. Mark the plastic temple at this point and at a second point 8 mm farther down the temple (Figure 10.60, *A*).

Cut the temple off at the second mark (see Figure 10.60, *B*), and throw out the cut off end (see Figure 10.60, *C*). Using a razor blade or an X-acto knife, cut through the plastic at the first mark to the depth of the metal core all the way around the temple (see Figure 10.60, *D*). Slip the 8-mm piece of plastic off (see Figure 10.60, *E*). It may be necessary to file and buff the plastic around the core wire to a smooth and somewhat tapered shape so that the transition between plastic temple and replacement cable appears natural.

The replacement cable should be heated with a hot air frame warmer for 20 to 30 seconds and slipped onto the exposed 8-mm temple core wire (see Figure 10.60, *F*). When the replacement cable completely covers the core wire, the whole temple should be cooled in water to contract the replacement cable firmly around the core wire. Assuming the appropriate color match has been made, the finished

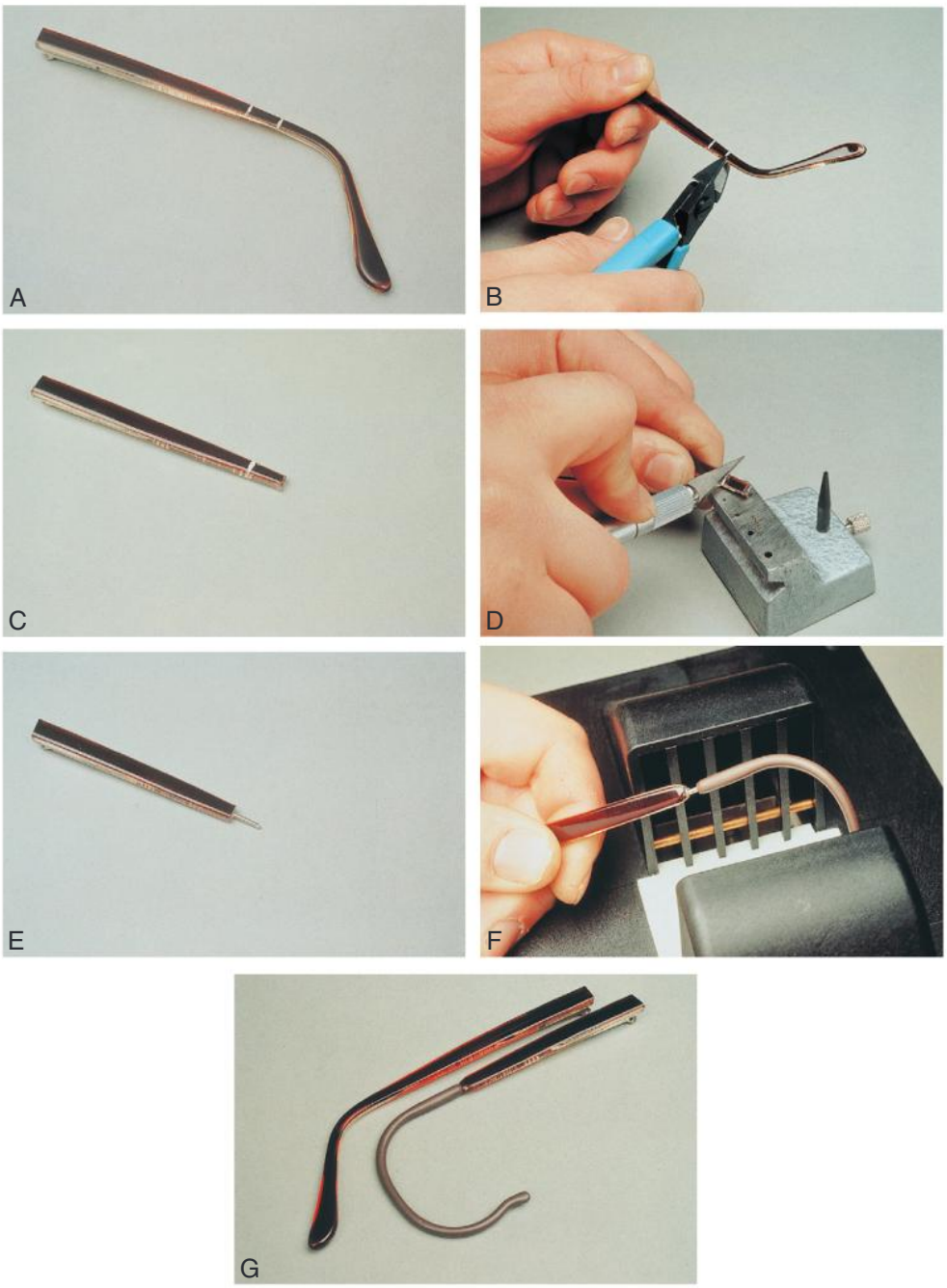

Figure 10.60 **A,** Converting a plastic skull temple to a cable-style temple begins by making two marks on the temple. The position of the first mark in millimeters equals the desired cable temple length minus the length of the replacement cable end. The position of the second mark equals first mark location plus 8 mm. **B,** The plastic temple is cut off at the location of the second mark. **C,** The temple has been cut at the second mark. **D,** The plastic between the first mark and the cut end is cut then stripped from the core wire. **E,** This shows the exposed core wire as it appears before adding the replacement cable end. **F,** After tapering and polishing the cut area of the plastic temple, the replacement cable end is slipped over the exposed 8 mm of core wire and heated. **G,** The skull-to-cable conversion is complete.

product should look as if it were originally intended to be a cable-style temple (see Figure 10.60, *G*).

Shortening Plastic Temples

It may be possible to special order a shorter pair of temples from the manufacturer if the current pair for a plastic frame is unacceptably long. This option should not be overlooked.

If this option is not viable, there is a method that can be used to shorten the length of plastic temples.[7] It requires care, or the results may reveal the modification. This technique is used when no other satisfactory frame is available and is done with the full knowledge and consent of the wearer. The procedure parallels that used to shorten the length of a metal temple having a plastic cover.

To begin, heat and straighten the plastic temple. With a sharp knife or razor blade, cut around the metal core of the temple about ½ inch in front of where the temple bend should be positioned. If the cut is made to the depth of the metal reinforcing wire, the end of the temple may be pulled off the wire. If it does not pull off easily, heat the temple again.

Next, cut off a section of plastic from the loose temple end adjacent to the first cut. The amount removed should equal the amount that the temple needs to be shortened. Now, cut off the end of the metal reinforcing wire. (The amount of wire cut away should be slightly longer than the amount that the temple needs to be shortened.)

Slip the plastic end of the temple back on the wire. Reseal the two pieces with acetone. After the area has dried and hardened, it may be filed and buffed.

REPAIRING THE HINGES

The hinge area of a frame is especially susceptible to damage. A blow or other impact to the side of the head can break the hinge area by forcing the joint between the temple and the front to open farther than it was designed.

Hidden Hinges

Most plastic frames have a hinge anchored directly in the plastic instead of the older method of being fastened with rivets and a shield. Such a construction is referred to as a *hidden hinge.*

To repair a loose or damaged hidden hinge, it is necessary to have either a soldering iron or preferably Hilco's Hot Fingers II™. The Hot Fingers II™ unit is considerably easier to use than a soldering iron because it has tips included that allow better contact between the hinge and the headed metal tips of the unit. The Hot Fingers II™ offers convenience. This includes the ability to pick up small parts with the tip of the probe (Figure 10.61) and a foot switch for instant heat.

Figure 10.61 The probe of the Hot Fingers unit allows the object being heated to be grasped easily. The Hot Fingers unit may be used to replace or repair hidden hinges, to do repairs on plastic frame breaks, and to add adjustable nose pads to plastic frames.

Repairing a Loose Hidden Hinge

To repair a loose hidden hinge, begin by removing the temple. Hold the tip of the heating unit to the loose hinge until the hinge becomes hot enough to begin to melt the surrounding plastic. First make certain that the hinge is not crooked, then plunge the hot frame area into cold water (Box 10.3).

Repairing a Hidden Hinge that Is Completely Torn Out of the Frame

If a hinge has been torn completely out of the frame, it may be repaired using the sequence given here and summarized in Box 10.4:

1. Using an old junk frame made of the same type of plastic as the one being repaired, cut off very small pieces of plastic. Alternatively, use virgin plastic pellets available from an optical supplier.
2. Put a few small pieces into the hole where the hinge belongs. Replace the hinge in the hole, making absolutely certain that it is straight. Hold the hinge in place with the Hot Fingers tool (Figure 10.62) or touch it with a soldering iron until the metal becomes hot enough to cause the plastic around it to remold itself to the hinge.
3. Plunge the whole area into cold water to harden the plastic.
4. Trim any excess plastic off using a razor blade.

Repairing a Hidden Hinge that Is Damaged or Broken Off[8]

If the barrels of the hidden hinge are split or broken, the old hinge must be removed and replaced with a new hinge. This is most easily done using the Hot Fingers unit because it allows a protruding hinge part to be grasped with the pincer-like end of the heated tool or, if the hinge is broken off flush with the frame, to be pried out with the pick-like edge of the tool.

To make the repair using the Hot Fingers, grasp the top and bottom of the barrel(s) of the hinge with the Hot Fingers probes (see Figure 10.62) and depress the foot pedal to heat the hinge. Once the surrounding plastic begins to soften, the hinge will start to rise out of the plastic. When this happens, take one point of the Hot Fingers and pry the hinge out. Use the pincers of the tool to grasp a new hinge by the barrel. The new hinge will have an "anchor" or wider area at the bottom to help hold the hinge in the frame. Heat the new hinge. Then take a

BOX 10.3 How to Repair a Loose Hidden Hinge

1. Remove the temple.
2. Hold the tip of a hot instrument on the hinge until surrounding plastic softens.
3. Check for hinge straightness.
4. Plunge hinge area in cold water.

BOX 10.4 How to Repair a Torn-Out Hidden Hinge

1. Cut off tiny pieces of a junk frame, make filings from a junk frame, or use virgin plastic pellets.
2. Put a few junk plastic pieces, a plastic pellet, or plastic filings in the hinge hole.
3. Place the hinge squarely in the hole.
4. Hold the tip of a hot instrument on the hinge until surrounding plastic softens.
5. Recheck the hinge for straightness.
6. Plunge hinge area in cold water.
7. Trim away excess plastic.

pellet of new acetate or a piece of plastic from the scrap frame. Since the hinge is hot, the plastic should stick to the hinge (Figure 10.63). Place the hinge base with the scrap plastic into the hole in the frame. Heat the hinge again. As it is heated, it will begin to sink into the plastic. Continue heating until the base of the hinge is flush with the surface (Figure 10.64). Remove your foot from the foot switch to turn off the heat, but do not let go of the hinge. Hold it steady for about 10 seconds to let the frame and hinge cool without moving. This will help set the hinge more securely in the frame. Last, plunge the frame in cold water.

After repairing a hidden hinge, the temple is put back on the frame front. Check that the temple spread is correct. *If the temple is spread too far,* the hinge has not been sunk deeply enough into the plastic. Remove the temple and reheat the hinge until it sinks a little deeper. *If the temple will not open far enough,* the hinge is sunk too deep. Instead of trying to pull the hinge out to some degree, simply file the butt portion of the temple as during standard alignment of a frame.

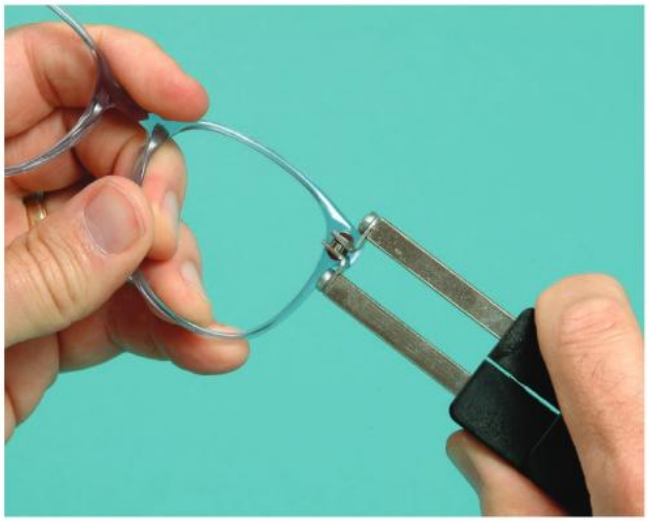

Figure 10.62 The Hot Fingers is used to grasp a torn out hidden hinge, put it back in the frame front, and heat it so that the plastic will be remolded around it.

A note on frame materials—This method works for frames made from cellulose acetate, propionate, polyamide, nylon, and carbon fiber. It will not work on frames made from Optyl. The filler material used to secure the hinge must be the same material as the frame being repaired. In other words, if the frame is made of nylon, use only nylon scrap for filler, acetate for acetate, and so forth.

Repairing an Optyl Hidden Hinge

At the time of this writing, it is almost impossible to repair a hidden hinge on an Optyl frame without a Hot Fingers unit. This unit is the only piece of equipment that appears to be capable of getting the hinge hot enough to melt Optyl.

To make the repair, grasp the broken hinge with the Hot Fingers and suspend the frame in mid-air. Use the other hand to lightly hold the other side of the frame so the frame will not fall when the hinge comes out. Begin heating the hinge.

After about 20 seconds, the material around the hinge will start to smoke (Figure 10.65, *A*). Let the frame drop away from the hinge without applying pressure. Trying to pry a hinge out of an Optyl material frame will cause the material to shatter. It should be burned out instead of pried out. Once the hinge is out, cool the cavity in cold water.

Next, clean out the cavity (see Figure 10.65, *B*). This is done with a small burr using a Dremel tool. Be sure all burnt material is removed and the hole is deep enough for the new replacement hinge. (Try putting the new hinge in the hole ahead of time to make sure the hole is deep enough.)

When the hole is deep enough, put two or three drops of strong adhesive or epoxy in the hole. Place the new hinge in the hole so that it is seated properly and at the correct angle. Allow the adhesive to dry overnight.

Riveted Hinges

A frame constructed with riveted hinges is no longer a common construction. The structure that usually gives way in a plastic frame with riveted hinges is not the hinge, but the rivets that hold the hinge to the frame. A riveted hinge used to be identifiable by a visible shield on the outside of the endpiece or the two silver rivets on the front or temples. However, frames may be designed to have a retro look and have these

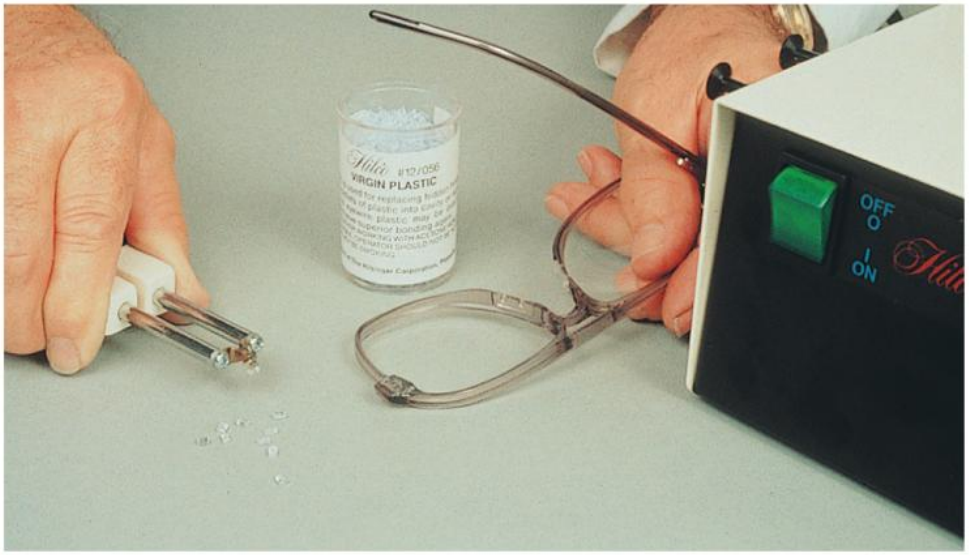

Figure 10.63 Instead of using plastic filings or cut-up pieces from an old frame, it may be helpful to purchase virgin plastic pellets to fill in the extra space when replacing or repairing a hidden hinge. (Courtesy Hilco, Plainville, Mass.)

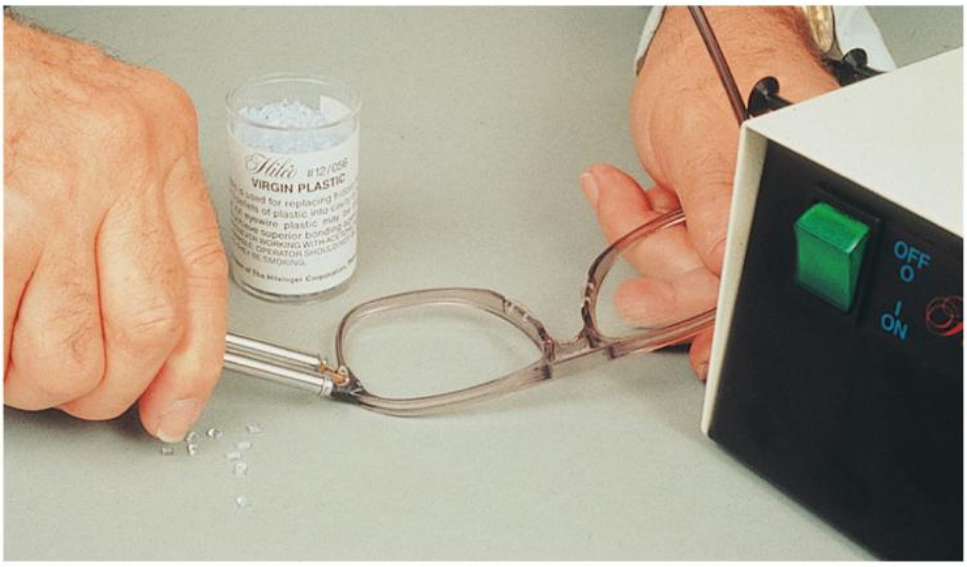

Figure 10.64 The hinge is placed back into the hole and heated until the base of the hinge sinks into the plastic and is flush with the surface. (Courtesy Hilco, Plainville, Mass.)

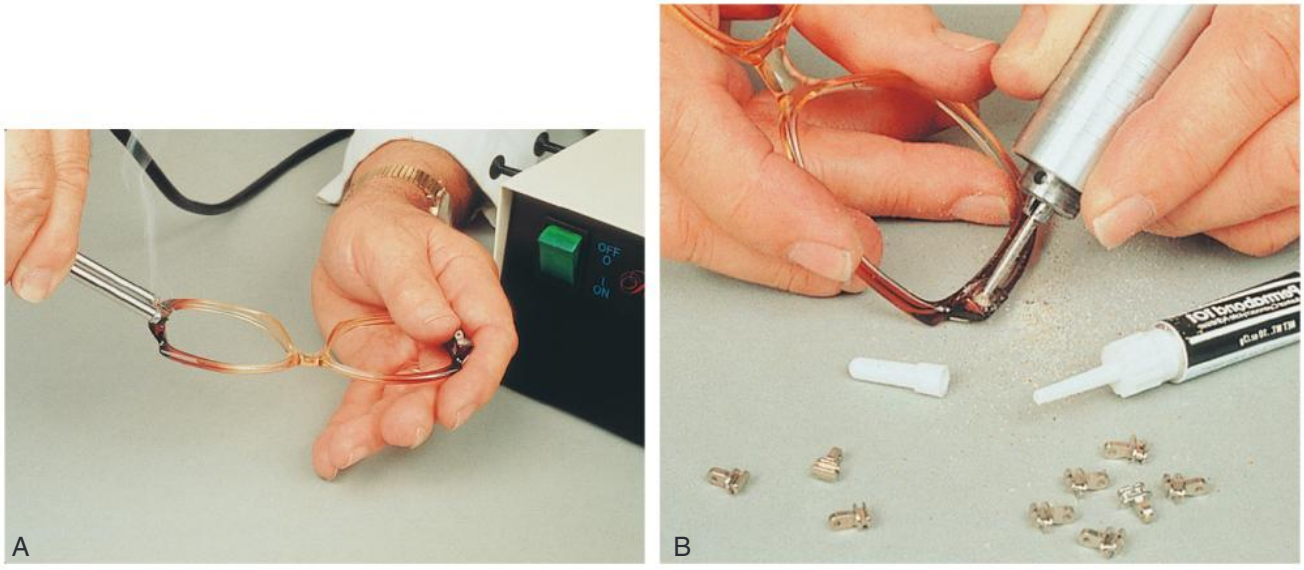

Figure 10.65 **A,** When removing a hidden hinge from an Optyl frame, the hinge must get hot enough to burn its way out. It is already possible to see smoke leaving the hinge area. **B,** After the hinge has been burned out of an Optyl frame, the hole that remains should be cleaned out with a small burr so that the hinge will bond well when glued in place. (Courtesy Hilco, Plainville, Mass.)

characteristics as part of the outward appearance without having a riveted hinge. With actual riveted hinges, the rivets are attached to the shield. When the barrels of the hinge break, both hinge and shield must be replaced.

PLASTIC BRIDGE REPAIRS

Ordinarily, if a frame has a broken bridge, it takes less effort and looks better to replace the entire frame or frame front than to repair the bridge. (Realistically, a broken bridge takes too long to repair and is not cost-effective.) On occasion, a different frame can be used, if perhaps only temporarily, until a proper replacement is secured. Sometimes, however, either by the wearer's choice or because no other expedient solution is possible, it is necessary to attempt to attach the broken halves of the bridge to each other. Here are several methods. Unfortunately, none of these produces a result that looks very good when finished.

Broken plastic bridges can be repaired using a variety of glues, several forms of wire braces, or several possible combinations of materials and methods.

Note: Individuals with broken frames may order a new pair of glasses but request that their old frame be repaired temporarily. It is prudent to require a deposit for the new glasses. With the repaired frame they are no longer in crisis and may not pick up and pay for the new pair.

Glues

There are several types of glue that can be used to cement the broken parts of bridges back together. Some of these can also be used in conjunction with wire braces; these applications will be discussed in the following sections.

Epoxy. The use of epoxy glue will result in a strong repair. There are a number of different types of epoxy on the market. Using a type especially designed for plastic will help. One such epoxy is a super-adhesive called Plastic Welder and dries to 80% strength in 15 minutes and full bond strength in 1 to 2 hours. Plastic Welder is made by Devcon Corp., Danvers, Mass.

Although different types of epoxy glues require varying amounts of time to dry, the major problem is holding the two parts together properly until the epoxy is set. A special dual-spring vise, used by jewelers, is especially effective for this task. If this vise is not available, make a holding apparatus from modeling clay. Surround the parts with enough clay to hold them in alignment.

"Instant" Cements. There are a number of quick-drying cements suitable for eyeglass frames that are sold in hardware and other stores. Cements marketed specifically for the purpose of repairing eyeglass frames are sold through optical supply houses.

Only a small amount of glue is required and will repair almost any break as long as the surfaces are clean, dry, and fit absolutely flush. The glue dries in seconds, so no special holding device is necessary. Once bonded, it holds, although the permanency of the bond is unpredictable and can rebreak unexpectedly.

Wire Braces

Several methods of repairing a broken bridge use wires as braces. The plastic is best drilled by using a small drill bit in either a hand or variable-speed drill; a high-speed electric drill will melt the plastic and cover the drill bit with melted plastic.

Twisted Wire. Drill a hole *perpendicular* to the frame front in each broken half of the bridge. Cut a U-shaped piece of a wire brace or paper clip, and insert one end through each hole (Figure 10.66, *A* and *B*). Twist the protruding portions of the clip about each other with small pliers until the bridge is held securely together (see Figure 10.66, *C*). Clip away the excess wire, and file the sharp edges smooth (see Figure 10.66, *D*).

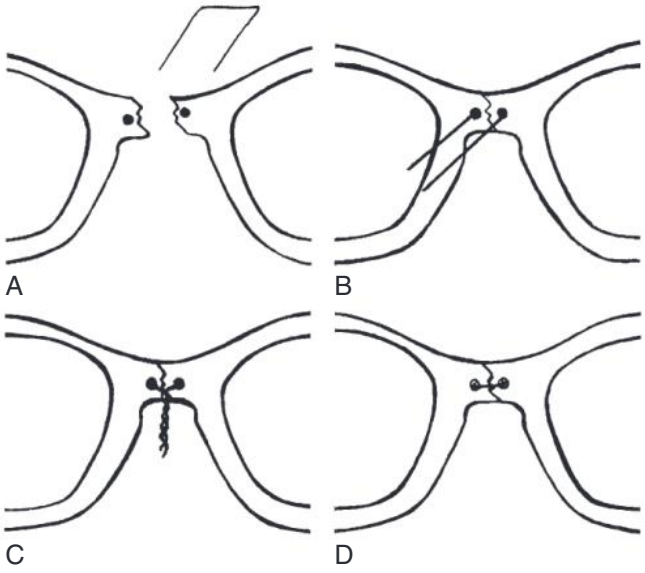

Figure 10.66 **A-D,** One functional (but unsightly) method of repairing a broken bridge with a wire brace.

This method works best when used in combination with glue or epoxy resin.

Imbedded Core Wire. A hole is drilled into the center of each half of the broken surface *parallel* to the frame front (Figure 10.67, *A*). The two halves of the bridge are pushed together over a small, thin, stiff piece of wire reinforcement, such as is used in frame temples. The holes should have the same diameter as the wire (see Figure 10.67, *B*).

This method works best when used in combination with glue or epoxy resin.

Stainless Steel Screws and Super Glue.[9] A better version of the imbedded core wire that was shown in Figure 10.67 is accomplished by using stainless steel screws and super glue.

Using a 0.0430 (No. 57) drill bit, drill *two* holes into *one* broken half of the bridge. Next, screw a 1.4-mm diameter stainless steel screw into each hole but not all the way in. Leave enough of the screw sticking out so that the screw head can be clipped off and still have 3 to 4 mm of threaded screw sticking out. With the screws securely in the drilled half of the bridge, clip the end off so that 3 to 4 mm of the screws are left protruding.

In the other broken half of the bridge, drill two holes in as close to the same location as possible, using a slightly larger drill bit. Try to put the two pieces together to see if they will fit correctly. It may be necessary to open up the holes slightly larger to ensure a flush, even fit.

When everything fits properly, put a couple of drops of super glue on the screw threads and press the two halves together. The bridge should be allowed to dry overnight before the frame is used.

Imbedding Staples Using the Hot Fingers Unit. One effective method uses the Hilco Hot Fingers unit to repair a broken bridge.

To repair a bridge using the Hot Fingers unit, first repair the break using glue. The Hot Fingers unit has a staple adapter that allows for easy

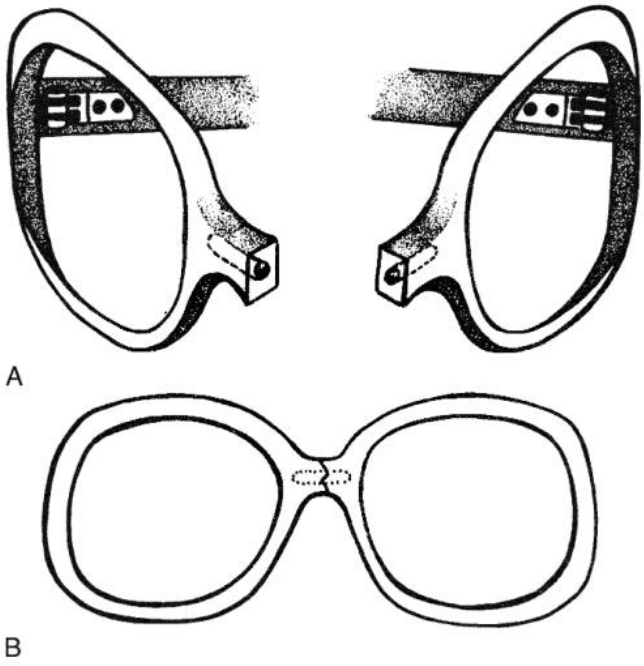

Figure 10.67 **A,** To repair the bridge, holes are drilled into the broken parts of the bridge parallel to the frame front. **B,** Glue is applied to both halves, and a thin wire (such as a piece of the stiff wire reinforcement used in frame temples) is inserted into the broken parts. The parts are pressed together.

insertion of a ¼-inch industrial staple. Place the staple ends into the adapter holes (Figure 10.68). Depress the foot pedal to heat the staple. Because the staple is thin, it will heat quickly. Slowly and firmly press the staple into the back of the frame bridge so that one staple leg is on either side of the break (Figure 10.69). Do not stop pressing the staple into the frame when the staple top is flush with the surface of the frame bridge. Instead, keep pressing the staple into the bridge. The staple should be imbedded approximately halfway through the thickness of the bridge. This will give extra stability to the broken area and hide the staple somewhat better.

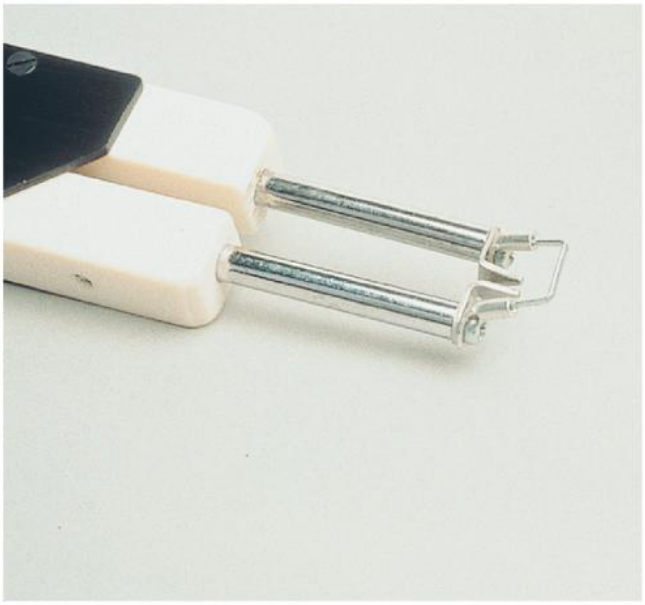

Figure 10.68 The Hot Fingers repair unit can be used to fix a broken bridge with a commercial grade ¼-inch staple. The staple is grasped securely with the staple adapter. (Courtesy Hilco, Plainville, Mass.)

Once the correct depth is achieved, take your foot off the foot pedal and hold the staple in place for approximately 10 seconds. Next, cool the bridge area in water and clip off the protruding ends of the staple. The ends should be filed smooth. If the design of the bridge allows, a second staple can be inserted through the top of the bridge for added stability (Figure 10.70).

Adding Nose Pads to Plastic Frames

Adding Cement or Stick-On Pads to a Plastic Bridge

It is possible to modify the shape and "width" of a plastic frame bridge to fit an especially narrow or unusual nose by using cement, stick-on, or otherwise mounted pads (Figure 10.71). They can be used to narrow the fit of the bridge or change the frontal and splay angles.

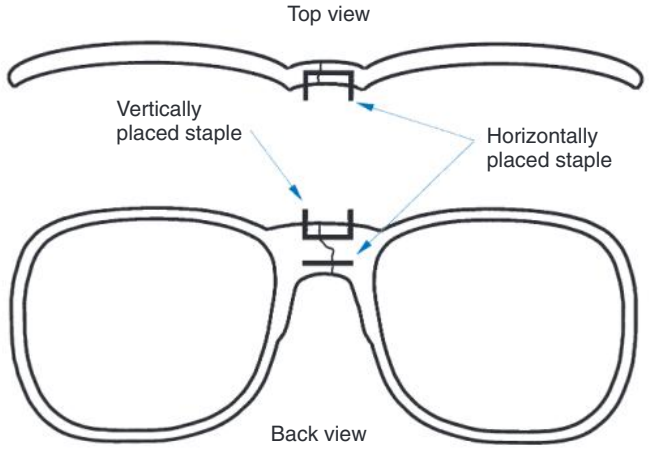

Figure 10.70 Recommended staple positions for repairing a plastic bridge. It is possible to repair a plastic bridge with only one staple. However, whenever possible, a second stable should be imbedded into the plastic. Afterward the ends are clipped off using cutting pliers and then filed smooth.

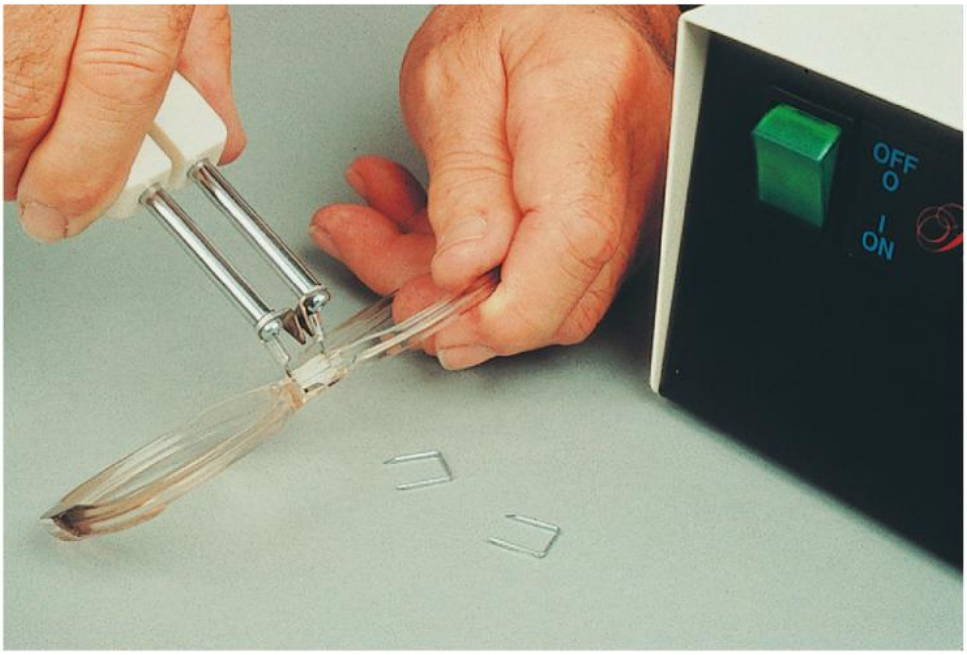

Figure 10.69 Placing the staple on the intended spot, the heat is turned on and the staple pressed into position. (Courtesy Hilco, Plainville, Mass.)

These pads are attached to the area of the frame that would normally rest on the nose and are secured in place with an adhesive. (Pads being added to Optyl frames are fastened in place with an epoxy resin.)

Such pads come in varying thicknesses. Some are uniformly thick and others are thicker at the "top" than at the "bottom" or thicker at the "front" than at the "back." Such wedge-shaped pads can be used to change both frontal and splay angles. Therefore, how the pads are applied (upside-down or right-side-up) will determine how well the finished product fits. (See Table 10.2 for how to apply such pads.)

If the fit of the bridge needs to be further modified with the new build-up pads in place, acetate pads can be filed to the right shape after they are dry.

Figure 10.71 Silicone nose pads mounted onto plastic frames with adhesive or with small drilled holes will not only reduce slippage but also slightly narrow the effective width of the bridge.

Applying Silicone or Acetate Press-On Pads Directly to a Plastic Frame Bridge

If a frame slips or is uncomfortable on the nose, it may be advisable to apply silicone nose pads directly to the frame bridge area. Silicone does not slip as easily. Acetate or silicone pads can be used to build up the frame bridge area to narrow the bridge or change the way the bridge fits. It is possible to purchase a whole kit (Figure 10.72) or only the pads.

To put these pads on the frame, use the marking template that comes with the kit. Mark the bridge area where the pads will rest (Figure 10.73, *A*). Next, drill holes where the bridge is marked (see Figure 10.73, *B*). The pad comes with two protrusions. These protrusions are pressed into the drilled holes (see Figure 10.73, *C*). When finished, the pad sits flush with the frame bridge.

Remember, since these added pads have thickness, they will cause an effective narrowing of the bridge. How much the bridge is narrowed depends on the thickness of the pad chosen. Decreasing the distance between pads will raise the frame on the face and increase the vertex distance slightly.

TABLE 10.2 How to Orient Wedge-Shaped Build-Up Pads for the Best Fit

Desired Effect	Recommended Action
Increase frontal angle	Orient pad with thick part up
Decrease frontal angle	Orient pad with thick part down
Increase splay angle	Orient pad with thick edge forward
Decrease splay angle	Orient pad with thick edge toward back of frame
Narrow bridge without changing angles	Use uniform thickness stick-on or press-on pads

Note: Adding pads directly to a plastic bridge will always have the effect of narrowing the bridge.

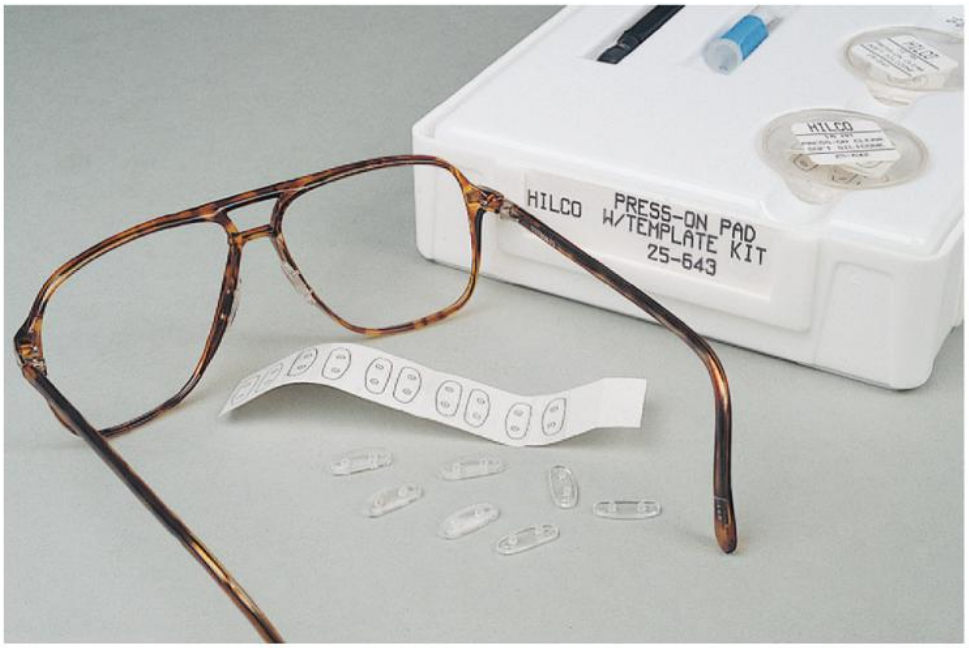

Figure 10.72 Here are the necessary items for mounting press-on build-up pads to a plastic frame. All items are available as a kit. Pads are available in either acetate (regular hard plastic) or silicone (pliable, slip-resistant material). (Courtesy Hilco, Plainville, Mass.)

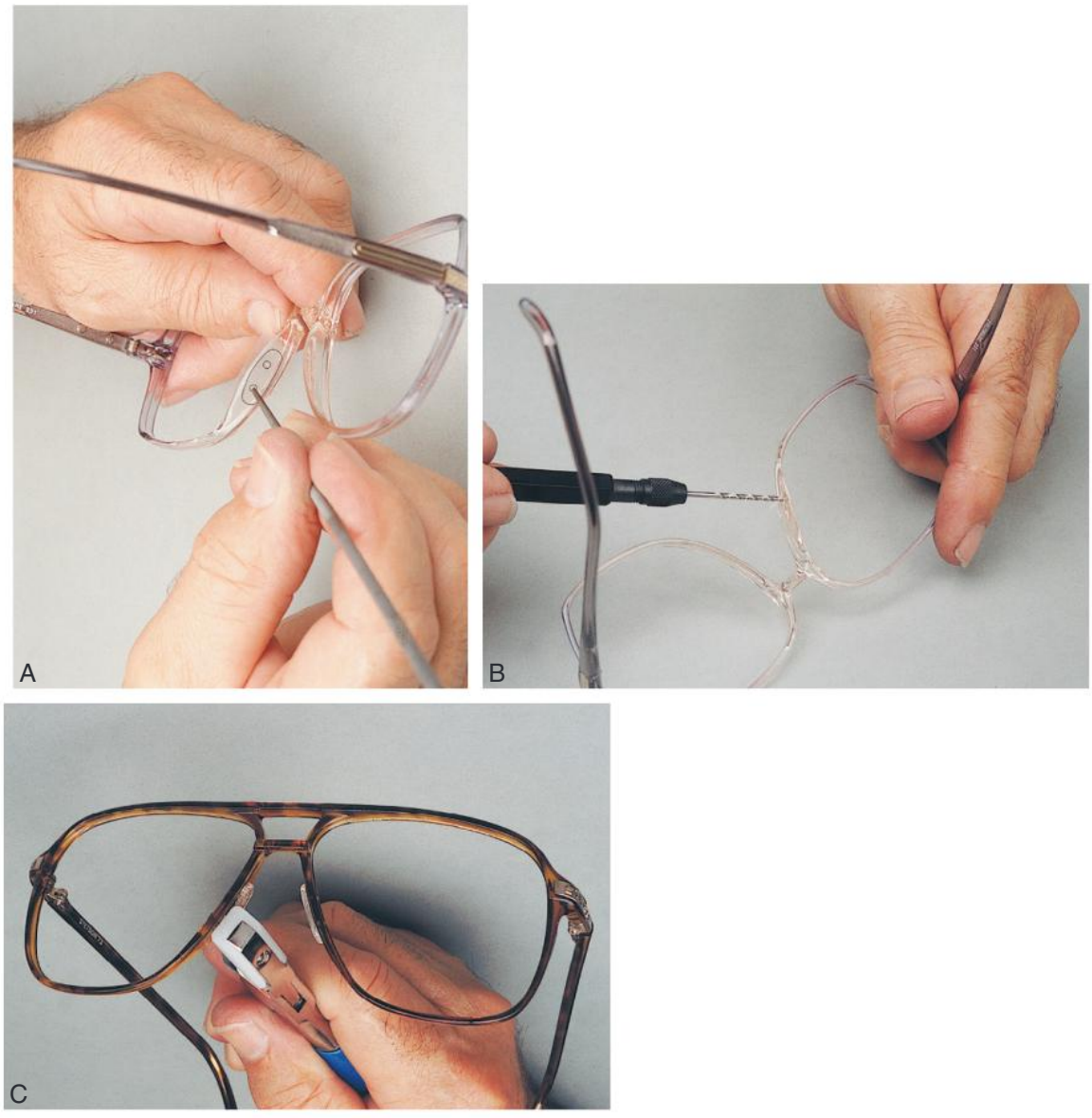

Figure 10.73 **A,** Either a measuring gauge or clear templates can be used to determine where the bridge area should be drilled. Here the template allows for exact premarking. **B,** A drill bit mounted in a chuck handle is used to bore out the needed holes for a replacement press-on pad. **C,** The protrusions on the backs of the press-on pads are squeezed into the drilled holes, mounting them firmly to the bridge. (Courtesy Hilco, Plainville, Mass.)

"Retrofitting" Plastic Frames with Adjustable Nose Pads

With so many possible frame styles available, by doing a careful frame selection, it should not be necessary to have to retrofit a plastic frame with adjustable nose pads. Yet, it is possible to add a pair of adjustable nose pads to a plastic frame if there is a sufficient thickness of plastic in the nasal area of the frame. The pad arms come individually or linked together as a pair. Both kinds are shown in Figure 10.74. The single pad arms are available in either low- or high-mount designs. The design chosen depends on the thickness of the bridge of the plastic frame. There must be enough depth of plastic so that the prongs on the pad arms will not pass through into the frame's lens bevel or otherwise go all the way through the plastic. (If the frame does not have enough thickness on the rim, then it may be possible to mount a one-piece bridge on the cross portion of the frame bridge.) Here is the sequence for mounting the pad arms:

1. First, decide which pad arms are most appropriate.
2. Next, file the existing plastic pads off the frame and smooth the filed area (Figure 10.75, *A*). Even though this area of the frame may not be visible when worn, it may be advisable to buff the area with a buffing wheel and polishing compound to restore the finish.
3. To be certain of getting both pad arms symmetrically placed (or a one-piece bridge properly centered, if this is being done), mark the proposed location of the prongs (see Figure 10.75, *B*). Use a template, if provided.
4. Mount the pad arms by heating the pad arm and pressing it in place using the Hot Fingers unit. If the Hot Fingers unit is not available, drill holes into the frame using a hand drill. it is possible to purchase a "Pad Arm Conversion Kit" that contains a small hand drill from Hilco.
   a. If the Hot Fingers unit is used, grasp the pad arm with the Hot Fingers tool. Place the pad arm prongs at the previously marked location (see Figure 10.75*C*).
   b. Turn the heat on with the foot switch.

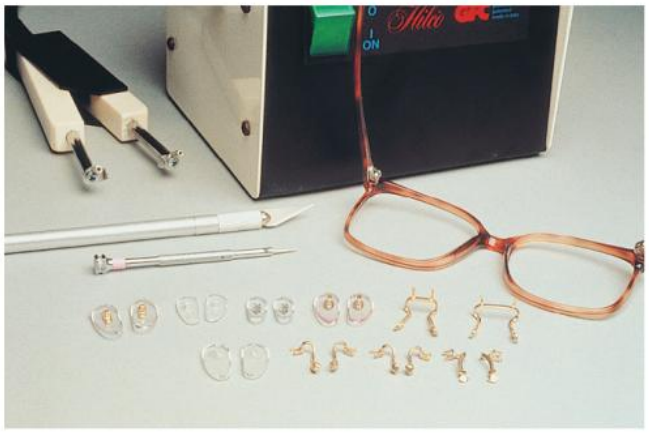

Figure 10.74 Adjustable pads may be added to a plastic frame if the frame has sufficient thickness in the area where the pad arms are to be mounted. Because of design variety in pad arms, chances of finding a suitable match are good. Here are some of the pad arms and pads available, along with tools that are used in mounting. (Courtesy Hilco, Plainville, Mass.)

c. Press the pad arm slowly into the plastic until it is fully seated.
d. Release the foot switch first and then the pad arm.
e. Immerse the frame in cold water and check for tightness.
f. It may be necessary to use a single-edged razor blade or small surgical knife to cut away excess plastic from around the point of attachment (see Figure 10.75, *D*).

5. Last, attach the pads to the pad arms.

Note: All these services are available through Hilco's repair center and through many local laboratories if the dispenser is uncomfortable with attempting them alone.

THE EYEWIRE AND LENS

Attempts to repair a broken plastic eyewire are often unsuccessful since the strain of the lens on such a small area tends to rebreak the repair when the frame is repeatedly taken off and put back on. Some forms of eyewire repair can be attempted in emergencies when it would be extremely difficult for the wearer to be without the glasses.

Repairs to the eyewire that do not relate to an actual break in the eyewire are generally more successful. These procedures concern the fit of the lens in the eyewire of the frame.

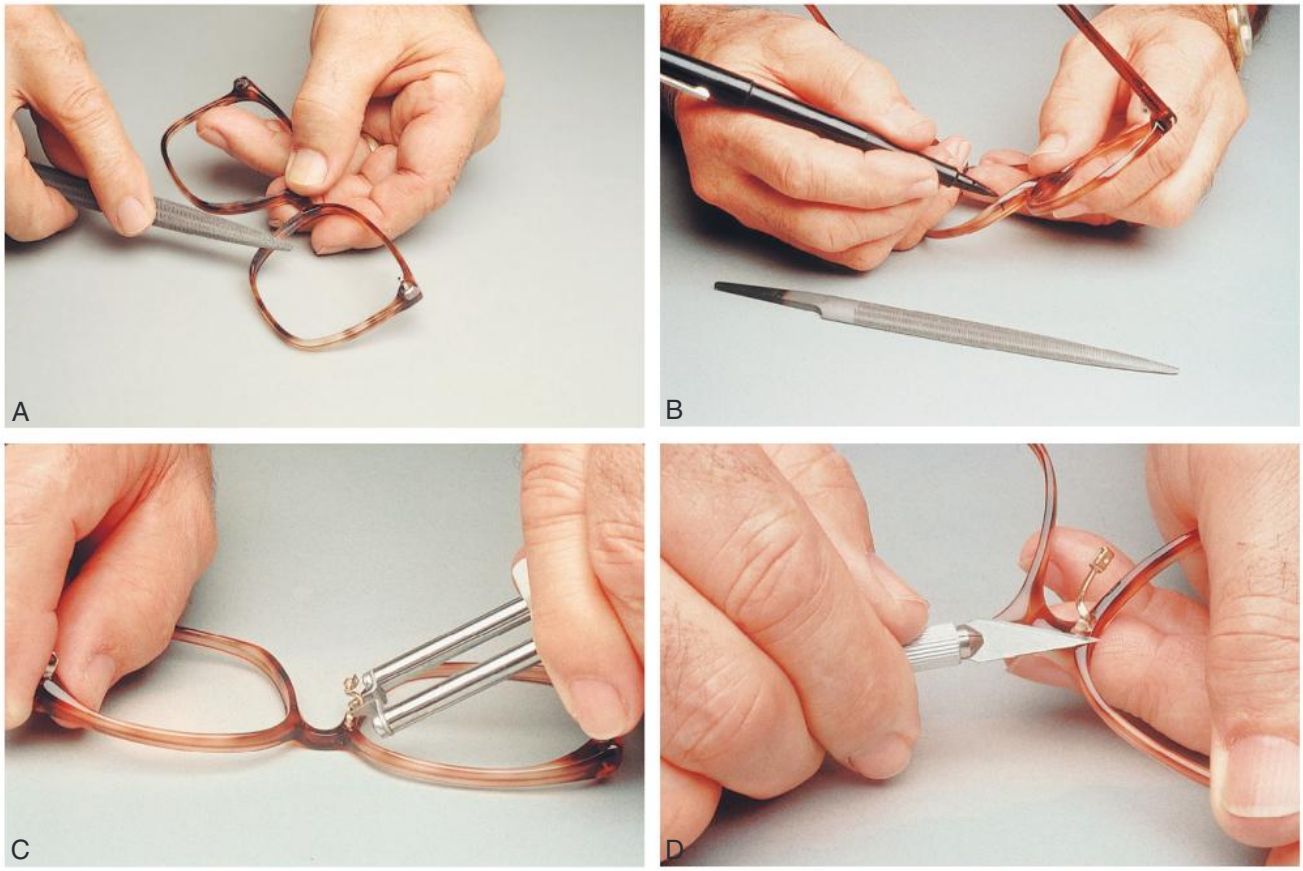

Figure 10.75 **A,** To mount single pad arms or one-piece pad-arm bridges to plastic frames, begin by filing off any existing plastic pads and file or buff the area clean. **B,** The next step in mounting pad arms to a plastic frame is to mark the proper position for the insertion. **C,** To mount the adjustable arm in the plastic frame, pick up the pad arm with the Hot Fingers tool. Carefully place the pad-arm anchor on the position marks. Firmly, but slowly, let the heated pad arm seat itself in the frame. Release the foot pedal and then the pad arm. Cool the frame in water and check the implant. **D,** After the pad arm has been securely mounted in the plastic frame, trim away any excess plastic with a razor blade or knife. (Courtesy Hilco, Plainville, Mass.)

Broken Eyewires

A broken eyewire usually requires a new frame. Until the new frame arrives, the wearer will need to rely on a backup pair of glasses. If no backup is available, then repair of the broken eyewire becomes the next best option.

It is possible to use either epoxy or fast-drying glue to repair the eyewire, but this is often not successful, since the most difficult part of repairing an eyewire is reinserting the lens without rebreaking the frame. Only that portion of the eyewire that is still intact should be heated. Even then, a frame rim repaired in this manner has a high probability of rebreaking.

Alternately, encircling the lens itself with glue and cementing the frame to the lens provides a means of holding the lens in the frame. This avoids both the necessity of reinserting the lens and of attempting to stretch the frame to encircle the lens. However, gluing the lens with epoxy in this manner should not be pursued if the lens is to be used again in another frame. Acetone or an acetone substitute should not be used either, because it will not adhere to lenses and will damage a polycarbonate lens. If the lens is to be used again, an inexpensive model-airplane-type of glue works best. When it comes time to remove the lens and use it again, scrape off the glue, and reinsert the lens in the new frame.

Lower Lens Edge Appears Out of the Frame

If the lenses have been inserted unsatisfactorily, particularly in a plastic frame, either the lower or upper portion of the lens may not fit properly in the eyewire and may give the impression that the lens is about to fall out of the frame.

If the lower eyewire of a *plastic frame* has been "rolled" during lens insertion, the lower edge of the lens will appear to be out of the frame. This condition can readily be noted by observing the frame from the side (Figure 10.76). To remedy this situation, remove the lens, and reheat the lower portion of the frame. Grasp the eyewire between thumb and forefinger, and rotate it back until the bevel again faces directly upward. Shield the fingers, if necessary, with a towel or other protective padding. The eyewire may have to be reheated and turned several times until it is completely aligned. When the eyewire is straight and the bevel directly vertical, the lens is reinserted, taking care not to roll the eyewire again.

If the lower edge of a lens in a *metal frame* appears to be out of the frame, the eyewire has not been properly shaped to follow the curvature of the lens edge. To correct this problem, remove the screw holding the eyewire. Hold the eyewire around the lens so that the bevel of the lens completely fits the groove of the eyewire. Then reinsert the screw. It may be necessary to prebend the eyewire to match the lower curve of the lens edge while the lens is out. This may be done with the fingers or preferably with eyewire shaping pliers (see Chapter 7, Figures 7.14 and 7.15).

Upper Lens Edge Appears Out of the Frame

If the bevel of the lens is excessively visible from the top, the frame probably does not conform to the curvature of the top of the lens (Figure 10.77). This situation is more likely to appear at the top than at the bottom of the eyewire because most lens shapes have a longer, straighter top. The curved front of the lens is more evident at the top, and the frame may not follow the curve as well. This is especially evident with high plus-powered lenses.

With a *plastic frame,* it is sometimes possible to heat the plastic without removing the lens. Pull the eyewire over the bevel, and, while holding it there, dip the lens and frame into cold water to fix the position. If this cannot be done, the lens should be removed, the eyewire heated and reshaped to match the lens curvature, and the lens then reinserted.

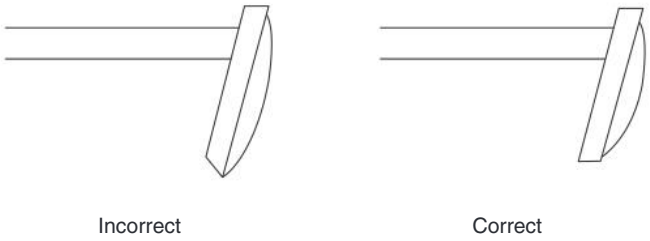

Figure 10.76 Observing the frame from the side for a lower eyewire that has been "rolled" during lens insertion.

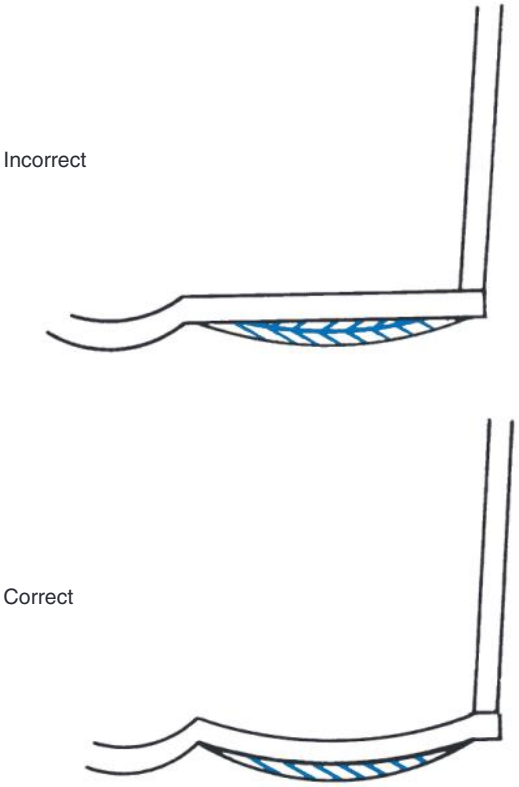

Figure 10.77 An exposed upper bevel gives an unsightly appearance but is readily correctable.

When the upper bevel of a lens in a *metal frame* sticks out, the lens must be removed and the eyewire reshaped. The methodology is the same as described in the previous section on reshaping the lower eyewire.

When the Lens Is Too Small for a Plastic Frame

If a lens which fits too loosely has been inserted into a plastic frame, it may rattle or rotate within the frame. When the frame appears to be too large for the lens, the lens must be remounted so that it is secure.

Overall looseness is corrected in cellulose acetate and propionate plastic frames by removing the lenses and shrinking the eyewire size by heating and chilling as described in Chapter 7. The process is repeated several times if necessary. When the eyewire reaches a size that is slightly too small to accept the lens, the frame is again reheated and the lens is inserted. After the lens has been inserted, immediate chilling of both lens and frame should secure the lens. (For how to "shrink" frames made from other materials, see Chapter 7.)

Occasionally, the lens appears secure, but a small gap or space is visible between the lens and the frame. The eyewire in this gap area is

heated and compressed against the lens bevel. Holding the plastic against the lens while immersing the frame and the lens into very cold water will further shrink the frame around the lens and secure the corrected position of the rim.

Sometimes a lens interliner (often called a lens liner or a lens washer) is used with plastic frames, even though it is intended primarily for metal frames. This is explained in the following section.

When the Lens Is Too Small for a Metal Frame

When a lens is loose in a metal frame, the most probable cause is that the screw holding the eyewire together has loosened. As an automatic first measure, tighten any loose screws.

If tightening the screw does not accomplish the desired result, it is probable that the lens has been edged with a circumference slightly too small to firmly fit the eyewire. For a new prescription, this is a quality control issue, and the glasses should be returned to the laboratory to be redone. However, if the problem is with an old prescription, there are ways to make the lenses fit better.

Acetate Lens Interliner (Lens Washer)

One method of correcting the problem is to loosen the screw and insert a plastic (acetate) lens liner, commonly referred to as a *lens washer,* in the bevel between the lens and the eyewire. This more common, nonadhesive form of lens liner comes in different thicknesses, is bevel-shaped on the outside to fit the eyewire, and contains a bevel on the inside to hold the lens. It is sold in a roll and may be cut to any desired length.

When using acetate liner, it is best to use the 0.010-mm interliner size. It is far less obtrusive than the 0.020-mm interliner. Here are three different ways to keep the liner in place while inserting the lens. The first is the currently recommended method:

1. Use a very small amount of super glue to hold the acetate interliner in place. To apply the glue, place a drop on some scrap paper and slide the back side of the interliner through the glue (Figure 10.78). Hold the interliner in the eyewire groove for 20 seconds, and it should stick.
2. Soak the liner in acetone. When the liner is soft and sticky; place it directly in the bevel of the frame. It will stick in the groove, and the lens can easily be inserted.
3. Tape the liner to the lens with transparent tape and insert the lens in the frame with the tape still in place. When the lens is securely positioned, cut the tape away using a razor or X-Acto-type knife.

Double-Sided Adhesive

Another form of liner is a double-sided, clear plastic tape. This tape is thin and hence inappropriate when the amount of looseness is considerable. It is much easier to use than the beveled liner, however, because it can be stuck directly to the lens bevel.

If the lens is extremely small for the eyewire and a sufficient amount of room is present, first apply the double-sided adhesive liner to the lens bevel, then fasten the thicker, beveled liner to the double-sided liner. This arrangement provides added bulk and simplifies the task by holding the thicker liner in position.

Lens Liquid Interliner

Instead of using conventional lens liner, there is a liquid liner that can be applied called Lens Cushion Soft Latex Lens Interliner (from Hilco) (Figure 10.79). It is dispensed right from the bottle into the "V groove" in the frame's eyewire and can be applied to the entire inside portion of the eyewire, if necessary. Liquid liner dries relatively quickly and can be used in almost any situation in which acetate liner would be used. It may be necessary to use more than one application depending on how loose the lens is.

This liquid liner should not be used in individuals with latex allergies. A latex-free lens liner called Lens Liquid Interliner LP-3004 is available from Amcon labs.

Gap or Air Space

If a gap or air space appears in a metal frame between the lens and the eyewire, place a strip of liner between the lens and the eyewire directly *opposite* the gap to force the lens into the gap (Figure 10.80).

The presence of a gap is obviously unsatisfactory workmanship for a new lens. Such repairs should only be used if the glasses were not initially supplied by you. Inform the wearer that, although the repair is less than satisfactory, it is the best that can be done without replacing the lens.

Figure 10.78 To hold acetate interliner in place in the groove while reinserting the lens, drag the outside of the interliner through a drop of super glue.

Figure 10.79 Instead of using conventional lens liners, there are liquid lens interliners that can be applied directly from the bottle to the groove of the frame. It dries relatively quickly and, when done properly, is not visible when the glasses are being worn.

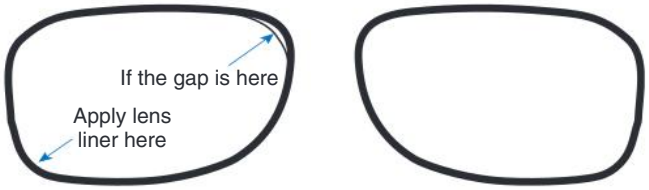

Figure 10.80 To fill an "air gap" between the lens edge and the frame, lens liner is applied in the area *opposite* the position of the gap.

It may be prudent to keep in mind that we live in an age of heightened legal liability. Should an eye injury result from an impact to repaired glasses that had a gap between the lens and the frame, there may be a liability issue, even in the case of informed consent.

Lens Slightly Loose

If the lens is only slightly loose in the frame, reduce the circumference of the metal eyewire itself by removing the eyewire screw and filing the barrel surface. The filing must be done evenly so that the barrel sections continue to fit flush (Figure 10.81). It is preferable to file the nonthreaded portion of the barrel rather than the side that accepts the tip of the screw. This is only possible on barrels that come together flat and not on barrels that have a wedge-shaped abutment (Figure 10.82).

The disadvantage of filing is that if the lenses are later changed and the same frame used, the new lenses could appear to be slightly too large for the eyewire unless each frame lens shape is individually retraced to actual circumference.

CLEANING THE FRAME

From time to time, because of repair work or just because of normal wear, frames need to be cleaned. Also, on occasion, the action of chemicals in perspiration, the use of tools on the plastic, or the circumstances of overheating a plastic frame may result in discoloration, blemishes, or marks in or on the plastic. In these instances, the defects need to be removed if the frames are in excellent operational order otherwise.

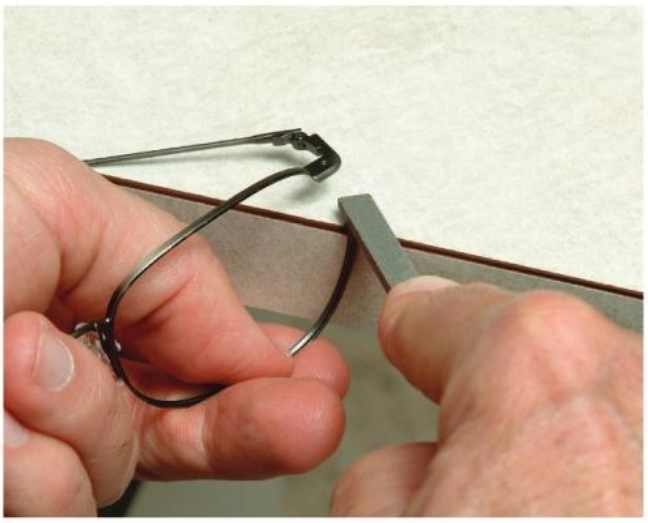

Figure 10.81 Care is taken to file evenly so that the barrel section will continue to fit flush as before.

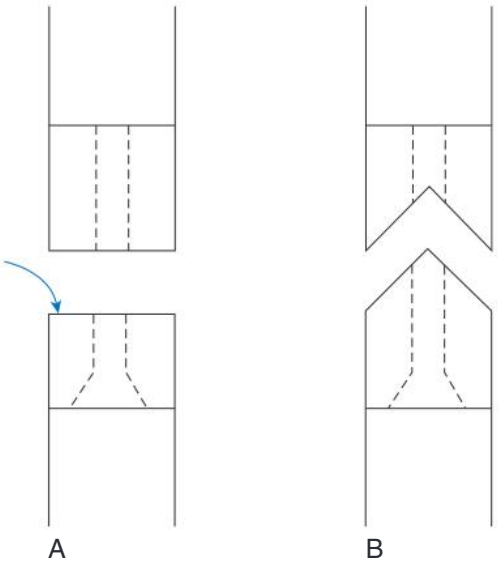

Figure 10.82 Reducing the circumference of the metal eyewire in the case of a loose lens by filing the barrel is only feasible on type **A.** The surface indicated by the arrow has been filed. Type **B** does not lend itself as readily to filing.

Cleaning Technique

Frames may be cleaned with ordinary soap and water so long as the soap contains no abrasive pumice material. An old toothbrush serves best for scrubbing hard-to-reach areas such as the pad arms or trim.

An ultrasonic cleaning unit is a most useful cleaning instrument. Leaving the frame (lens side up) in the small tank loosens dirt that might not otherwise be dislodged. After cleaning a frame in such a unit, be sure to check all screws for tightness, since the vibrations tend to loosen them.

The following types of frames or lenses should not be cleaned in an ultrasonic unit:

1. Frames with glued-in rhinestones or other small jewels should not be cleaned ultrasonically because the stones may be immediately dislodged or may fall out later.

2. It is not advisable to clean AR or vacuum-coated lenses in an ultrasonic unit.
3. Fortunately, glass lenses placed in a drilled mounting are almost nonexistent. However, if a pair of antique drill mounts with glass lenses were to be brought in for cleaning, glass lenses may break because of the intense vibrations of the ultrasonic unit.

Discoloration

Discoloration usually occurs on the inside of the temples of plastic frames where they contact the hair and the skin. It most often appears as a whitish film. With age, cellulose acetate and propionate frames may exhibit a film, which is caused by plasticizers within the material migrating to the surface.[10] In either case, a buffing wheel used with polishing compound will remove the discoloration and will also repolish the plastic.

When a buffing wheel is not available, apply acetone and oil with a cotton-tipped applicator and rub over the entire length of the temple in one direction. Each time the temple is brushed, it should be with fresh acetone and oil and in the same direction. Repeat this process as often as necessary until the color is restored. If acetone without oil is used, the brushing action must be rapid to avoid leaving prints in the softened surface. If the wet surface is blown on or exposed to moving air, condensation may again whiten the temple.

Surface Marred by Pliers

If the plastic has been marred by the jaws of pliers, an attempt to restore the surface can be made. Heating the frame at the damaged area will hopefully cause the compressed portion to expand back to its original dimensions. The area can be reheated repeatedly as long as the plastic is not overheated until it bubbles, because this would compound the problem. When it appears that the frame has re-expanded as far as is likely, the area is buffed with buffing compound on a rag wheel.

Restoring Finish on Optyl Frame Material

The finish of frames made from Optyl material can be damaged if the frame is inadvertently rubbed against a rough surface. If the frame surface has been marred, remove the defect by buffing the area.

To restore the sheen after buffing, coat the area with polyurethane finish such as is used in furniture refinishing. Either satin or glossy polyurethane will prove satisfactory.

Bubbles

Bubbles result from overheating the plastic and cannot be removed because they ordinarily extend well into the plastic.

An attempt to salvage the aesthetic appearance of the frame may be made, however, by filing the bubbled area smooth and then buffing it to restore the luster.

If the frame looks asymmetric as a result of the one area having obviously been thinned, the mirror portion of the frame is also filed and buffed to match.

SOLDERING

Soldering is the only possible way to repair a broken metal portion of a frame unless the entire front or temple is replaced. The techniques used for soldering spectacles are similar to those used for soldering jewelry and in the past were sometimes performed by jewelers. (It used to be common practice for jewelers to accept repair requests from eye care practitioners. However, this is now the exception, rather than the rule.)

If a frame cannot be replaced and must be soldered, it is advisable for most practices to send the frames to an optical repair center, rather than attempt such repairs on site.

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PROFICIENCY TEST

(Answers can be found in the back of the book.)

Screws

1. The threads of a barrel have been damaged during screw removal. Which of the following statements about this situation is false?
   - **a.** A self-tapping repair screw may be used to create new threads and seal the screw so that it will not back out.
   - **b.** A glass screw and hex nut may be used.
   - **c.** The hinge must be replaced with a new one.
   - **d.** A tap may be used to restore the threads.
2. When a pair of glasses has a temple screw that just keeps loosening up, which of the following responses is not a possible solution?
   - **a.** Seal the screw in place using a commercially available compound.
   - **b.** File on the head of the screw so that it cannot come out.
   - **c.** Tap on the tip of the screw with an optician's hammer so that it flattens out, becoming more rivet-like.
   - **d.** Replace the screw with a self-locking replacement screw having an epoxy type of coating on the threads.
   - **e.** Use clear nail polish on and around the head of the screw.

3. When removing a stuck screw, which of the following possibilities should NOT be used?
   a. Use penetrating oil to loosen the screw.
   b. Soak the endpieces of the plastic frame in acetone and then try to remove the stuck screw with a screwdriver.
   c. Use an ultrasonic cleaner to loosen the screw.
   d. Heat the screw area and then hold a birthday candle or paraffin wax against the barrel area to lubricate it.
   e. Grasp the top and bottom of the screw with Hot Fingers or touch the screw with a soldering iron to heat the screw.
4. When removing a screw that has the head broken off, which of the following possibilities should NOT be used?
   a. Use a screw extractor, and approach the screw from the tip to screw the remaining portion out the bottom of the barrels.
   b. Use punch pliers to remove the screw.
   c. Drill out the screw.
   d. All of the above methods could be used to remove a broken-off screw.
5. True or false? Self-tapping screws are longer than necessary so that they may be used in frames of different barrel sizes. The extra screw length does not need to be cut with cutting pliers but simply broken off with any normal thin-nosed pliers that are able to grip the tip of the screw.
   a. True
   b. False
6. If a titanium screw starts to bind and not go into the barrels, what is the best thing to do?
   a. Remove the screw and try again. If this does not work after several tries, use a drop of oil in the barrel.
   b. Remove the screw and try again. If this does not work after several tries, force the screw in. Titanium is hard enough that it will rethread the barrel itself.
7. A screw is broken off in the barrel of a frame, and the head of the screw is gone. Other methods of removal have failed, and the screw cannot be removed without drilling it out. How should it be drilled out?
   a. From the top of the screw using oil as a lubricant for the drill.
   b. From the top of the screw. NO lubricant is used as that causes the drill to "float" away from the desired location.
   c. From the bottom of the screw using oil as a lubricant for the drill.
   d. From the bottom of the screw. NO lubricant is used as that causes the drill to "float" away from the desired location.
8. Identify the accurate statement about replacement spring hinge screws.
   a. They have hexagonal heads so that it is easier to drive them in.
   b. They come with lock nuts so they will not loosen up.
   c. They have tapered tips so they can get a start into the barrels easier.
9. A "top hat bushing" is used with what frame type or frame part?
   a. Spring hinges
   b. Rimless mountings
   c. Combination frame chassis
   d. Nylon cord frames
   e. Trim on plastic frames
10. True or false? Replacement screws with an epoxy coating on the threads will neither back out once they are tightened down nor can they ever be removed.
    a. True
    b. False
11. What is the most common diameter for optical screws?
    a. 0.5 mm
    b. 0.9 mm
    c. 1.4 mm
    d. 1.7 mm
    e. 2.0 mm

Nose Pads

12. Clip-on, screw-on, twist-on, push-on, bayonet, split-clamp, stirrup, and rivet are all terms which apply to:
    a. types of temple endpieces.
    b. types of rimless mountings.
    c. types of nylon cord mountings.
    d. types of adjustable nose pads.
13. True or false? A frame persists in sliding down the nose even after being properly adjusted for the wearer. If the pads are not silicone, it may be helpful to replace them with silicone pads.
    a. True
    b. False
14. What is NOT a possible way to add silicone nose pads to a plastic frame?
    a. Use a silicone pad that has stick-on adhesive.
    b. Drill the nasal area of the frame, and press the protrusions of a specially constructed silicone nose pad into the holes.
    c. Mount adjustable pad arms to the frame, and put silicone pads on these pad arms.
    d. All of these methods are satisfactory.
15. At the time of this writing, the two most common types of adjustable nose pads are:
    a. push-on and twist-on.
    b. twist-on and screw-on.
    c. rivet and twist-on.
    d. screw-on and bayonet.
    e. screw-on and push-on.
16. What is a good material to use for a nose pad replacement when the wearer is allergic to standard nose pad materials?
    a. Nickel
    b. Propionate
    c. Crystal
    d. Acetate

Temples

17. True or false? Some metal temples with plastic coverings over the bent-down portions can be lengthened somewhat by heating and straightening the plastic endpiece, pulling it out the necessary distance, and rebending it at the proper position.
    a. True
    b. False
18. True or false? If a left replacement temple is needed and the only temple available is a right temple, you could try to use the right temple anyway and reverse the direction of the bent-down portion.
    a. True
    b. False
19. True or false? It may be possible to shorten a metal temple by removing the earpiece, clipping off a piece of the core wire, and putting the earpiece back on again.
    a. True
    b. False

Hinges

20. The presence of two small circular silver dots on a frame endpiece or temple butt is a sure indication of the presence of rivet hinges.
    a. True
    b. False

Bridges

21. True or false? There are several different ways to repair a broken bridge. However, it is best not to combine two different bridge repair methods.
    a. True
    b. False
22. True or false? Without a Hot Fingers unit, it is not possible to mount adjustable pad arms to a plastic frame.
    a. True
    b. False

Eyewires

23. When the lens is slightly small for the eyewire of a metal or combination frame, which tool might prove helpful, depending on eyewire closure construction?
    a. Optician's hammer
    b. File
    c. Half-padded pliers
    d. Tap
24. True or false? Marks on a plastic frame made by pliers are never repairable.
    a. True
    b. False
25. What could be used to *temporarily* hold a lens in a broken eyewire? (The lens will be re-used in a new frame.)
    a. Clear nail polish
    b. Soldering iron
    c. Model airplane glue
    d. Lens liner
    e. Super glue
26. How can lens liner be made to stay in position while a lens is being reinserted in the frame?
    a. Tape it in place.
    b. Fasten it to the lens with a thin, double-sided material.
    c. Soak the liner in acetone.
    d. Drag the outside of the liner through a drop of super glue.
    e. All of the above methods may be workable.
27. To eliminate a gap between the lens and a metal eyewire, the best alternative is to:
    a. place a strip of lens liner at a point exactly opposite the gap.
    b. place a strip of lens liner in the gap area.
    c. heat the lens while it is in the frame, and then allow it to cool back to room temperature.
28. True or false? One advantage of cellulose acetate and propionate frames is that if the lens is too small, it may be possible to heat the frame and then plunge it in ice-cold water to shrink the frame.
    a. True
    b. False

Cleaning

29. Which frame type should *not* be cleaned in an ultrasonic unit?
    a. Metal frame
    b. Jeweled frame
    c. Plastic frame
    d. Nylon frame

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PART II

Ophthalmic Lenses

11

Review of Elementary Mathematical Principles

THE METRIC SYSTEM

It is best to be familiar enough with the metric system of measurement that one no longer thinks of it in relation to the English imperial system. For example, it is much simpler to know how long a centimeter is than to figure out what fraction of an inch it might be. This can be done without much effort since most rulers now have a metric scale on one edge. Additionally the interpupillary distance (PD) ruler, which no dispenser can be without, uses the metric scale exclusively.

The unit of measure upon which the metric system is based is the *meter* (m). All other units are expressed as either multiples or fractions of that unit.

Just as there are 10 *dimes* in a dollar, so also there are 10 *deci*meters (dm) in 1 m. Just as there are 100 *cents* in a dollar, so also there are 100 *centi*meters (cm) in 1 m. Just as the wormlike *milli*pede is reputed to have 1000 legs, so also does 1 m have 1000 *milli*meters (mm).

A kilometer also has reference to a thousand, but this time 1 kilometer = 1000 m.

Therefore:

$$1\,\text{m} = 10\,\text{dm} = 100\,\text{cm} = 1000\,\text{mm}$$

and

$$1\,\text{km} = 1000\,\text{m}$$

Weight measures are in multiples of 10 as well, retaining the same prefixes as the previously discussed linear measures. The basic unit of metric weight is the *gram*.

If conversion from metric to English linear measurements becomes necessary, conversion factors are:

$$1\,\text{m} = 39.37\,\text{in}$$

$$1\,\text{cm} = 0.394\,\text{in}$$

$$1\,\text{in} = 2.54\,\text{cm}$$

REVIEW OF ALGEBRA

Algebra uses positive and negative numbers and letters or other symbols to express mathematical relationships (Table 11.1). These relationships are used in formulas or equations. Letters or systematic symbols take the place of a number that is either unknown or subject to change to allow for dimensional variations.

Algebra offers versatility by allowing an equation to be altered to a new form for a specific need. For example, the formula:

$$a + b = c$$

is in the best order if a and b are known, and c is unknown. (If a is equal to 1 and b is equal to 2, what is c?) This form of the equation is not as easily used if a is the unknown. In this case, it would be better to transform the equation to make for greater ease in solving for a.

Transformation

To transform an equation, the components are moved from one part of the equation to another. If a component is moved across the equal sign, the sign of the number moved must be changed from plus to minus or minus to plus. To follow the logic behind a required change in sign, it is noted that the same number (or symbol for a number) may be added to or subtracted from both sides of an equation. If

$$1 + 2 = 3$$

the two sides of the equation are still equal even if 2 is subtracted from each side:

$$1 + 2 - 2 = 3 - 2$$

Therefore, if

$$a + b = c$$

then

$$a + b - b = c - b$$

Since

$$b - b = 0$$

then

$$a = c - b$$

and the transformation is accomplished.

Transforming when multiplication or division is involved is the same as multiplying both sides of the equation by the same number. For example, if

$$2 \times 3 = 6$$

Then

$$2 \times 2 \times 3 = 2 \times 6$$

or if

$$2 \times 3 = 6$$

then

$$\frac{2 \times 3}{2} = \frac{6}{2}$$

TABLE 11.1 Commonly Used Algebraic Symbols

Operation	Symbol
Addition	$a + b$
Subtraction	$a - b$
Multiplication	$a \times b$ or $a \bullet b$ or ab
Division	$a \div b$ or $\frac{a}{b}$
Quantity squared	a^2
Square root	$\sqrt{a}$

In each case the quantities are still equal, and the equation remains valid. Expressed in more generalized terms, if

$$a \times b = c$$

then

$$\frac{a \times b}{a} = \frac{c}{a}$$

and because

$$\frac{a}{a} = 1$$

then

$$b = \frac{c}{a}$$

The equation is the same as before, but it is expressed in a different form.

Naturally, if one side of the equation contains more than one term, both terms are affected by the transformation. For example,

$$ab = b + c$$
$$\frac{ab}{b} = \frac{b + c}{b}$$
$$\frac{a\cancel{b}}{\cancel{b}} = \frac{b + c}{b}$$
$$a = \frac{b + c}{b}$$

Use of Parentheses

When symbols are multiplied or divided or otherwise have a mathematical operation performed on them as a group, they are symbolically held together by parentheses. For example,

$$3(a + b) = c$$

means that both a and b are multiplied by 3. In fact, another valid way to write this equation would be:

$$3a + 3b = c$$

If the equation were written as

$$3a + b = c$$

without the parentheses, it would not be the same equation at all. Only a would be multiplied by 3, showing the importance of the parentheses. In a transformation, those items within parentheses are treated as a single item. For example,

$$x(a + b) = 2(c + d)$$

then

$$\frac{x(a + b)}{(a + b)} = \frac{2(c + b)}{(a + b)}$$

since

$$\frac{(a + b)}{(a + b)} = 1$$

then the equation becomes

$$x = \frac{2(c + b)}{(a + b)}$$

Positive and Negative Numbers

Positive and negative numbers are continuous with one another on the same number line. Both start at zero but begin "counting" in opposite directions (Figure 11.1). Nearly everyone uses both positive and

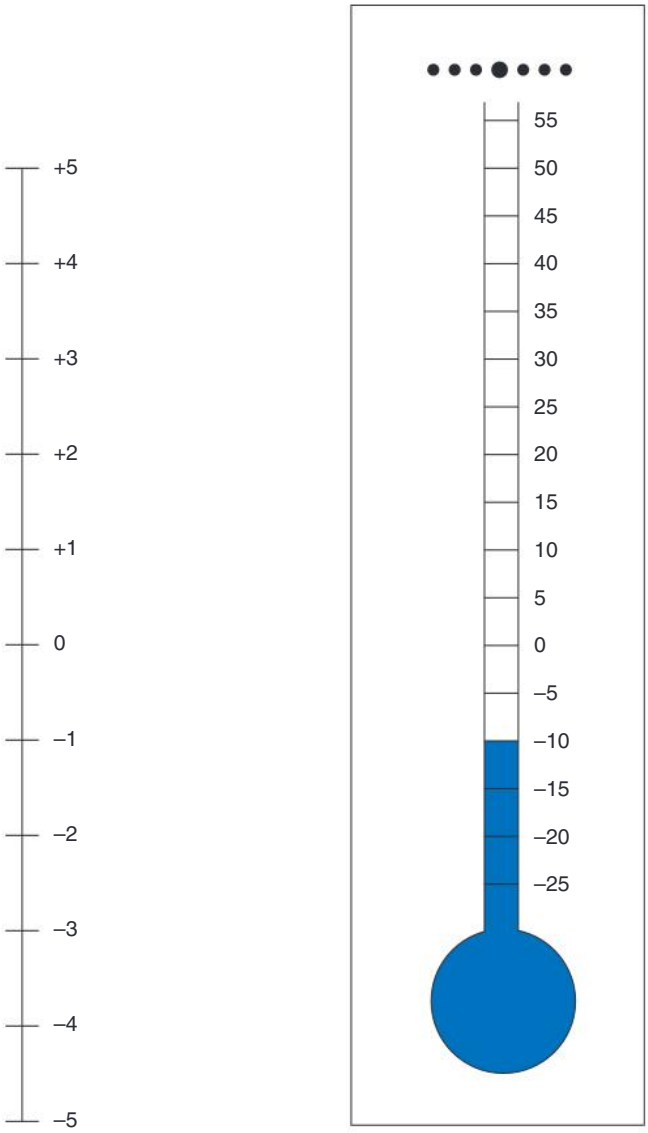


Figure 11.1 The concept of positive and negative numbers is easily illustrated by use of a number line as shown on the left. It is seen commonly on instruments, such as the thermometer.

negative numbers daily. For example, when the thermometer drops below zero degrees, negative numbers are used to describe the temperature. When something is indicated as being 300 feet below sea level, it can be said to be at −300 feet. In this case sea level is the zero point.

In working with negative numbers, one must remember how they relate in their distance from positive numbers. Again, this can be most easily illustrated using the thermometer concept. How many degrees colder is −10° than +10°? When the mercury drops from +10° to −10°, it travels 10 units to reach zero and another 10 units to reach −10°. The drop in temperature is a total of 20°.

In optics, this is most directly applicable to cylinder values. If the 90-degree meridian has a power of +2.00 D and the 180-degree meridian has a power of −2.00 D, how strong is the cylinder (Figure 11.2)? (The cylinder value is the difference in power between the two major meridians of a lens.) On a number line, such as found on conventional lensmeter scales, it is readily seen that a total of 4 units must be traveled in going from the +2.00 mark to the −2.00 mark. Since we are traveling in a minus direction, the value of the cylinder is −4.00 D. If we were going from the −2.00 mark to the +2.00 mark, we would be traveling in a plus direction, and the value of the cylinder would be +4.00 D.

Use of the Reciprocal

The reciprocal of a number is obtained by dividing that number into 1. For example, the reciprocal of 2 may be written as $1 \div 2$, or $\frac{1}{2}$, or 0.5. Conversely, then the reciprocal of 0.5 is $1 \div 0.5$, or $\frac{1}{0.5}$ or 2.

In optics, reciprocals are used to convert focal lengths into dioptric units of lens power. If the focal length of a lens is 0.20 m, the dioptric power of the lens is the reciprocal of that focal length.

$$\frac{1}{0.20\,\text{m}} = 5\,\text{D of lens power}$$

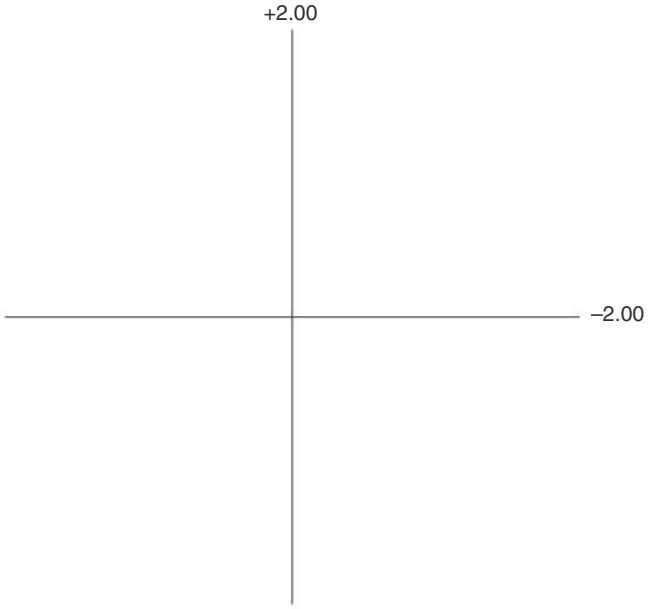


Figure 11.2 Illustrating the relationship between positive and negative numbers, the prescription shown on a power cross has a value of +2.00 −4.00 × 090. In this example, the difference between the positive and the negative meridian is the value of the cylinder in the prescription, which is 4.00 D. (When starting from the +2.00 value, the cylinder power would be −4.00 D. When starting from the −2.00 value, the cylinder power would be +4.00 D.)

Roots and Powers

When a number is multiplied by itself, it is said to be *squared*. For example, 10 squared = 100, which is another way of saying $10 \times 10 = 100$. "Squared" is abbreviated mathematically by a superscript 2 written above and to the right of the number. The number indicates that 2 units of that same number are to be multiplied by each other. Ten squared (10×10) would be written as 10^2. It may also be spoken of as 10 to the second *power*. If 10^2 equals 100, then the "root" from which the result of 100 has "grown" was the quantity 10 squared. Therefore, the *square root* of 100 is 10. To find the square root of a number, the operation is indicated by the symbol enclosing that number. For example,

$$\sqrt{100} = 10$$

A number can be "raised" to any given power; in other words, a number can be multiplied by itself any number of times. This operation is again indicated by a superscript:

$$10^3 = 10 \times 10 \times 10 = 1000$$
$$10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000$$
$$a^5 = aaaaa$$

and so forth.

When indicating that the quantity is multiplied by itself a given number of times, it is also possible to place the superscript outside a parenthesis. This indicates that the whole quantity within the parentheses is multiplied by itself the number of times indicated by the superscript.

For example,

$$(a \times b)^2 = (a \times b)(a \times b)$$

REVIEW OF GEOMETRY

Since geometry is used fairly often in optics, a basic understanding of it is essential. It might be said that the concept of geometry is built on a "triangular foundation," which is to say that understanding the mathematics of a triangle is the basis for understanding geometry.

The Cartesian Coordinate System

The Cartesian coordinate system is a method of graphical localization of a point in space. In two-dimensional space, which is a flat plane such as a sheet of paper, localization may be done with a paired set of numbers, x and y. These two numbers symbolize the horizontal and vertical locations of a given point with reference to an original point: x is the number of units to the right (+) or to the left (−) of the zero point, whereas y refers to the localized point above (+) or below (−) this point (Figure 11.3). The reference point, or *origin*, is specified as (0,0). The horizontal location (x) is always given as the first number in the pair and the vertical (y) as the second. The Cartesian coordinate system allows for ease and clarity of localization of any point, line, or geometric figure.

Triangular Forms

There are 360 degrees in a complete circle. The wedged end of a pie-shaped piece of the circle contains a given number of these 360 degrees. The number of degrees contained between the two edges of the piece of pie that meet at the point is the degree measure of the angle formed.

A triangle contains three such points, or angles. The sum of the three angles contained within a triangle always equals 180 degrees.

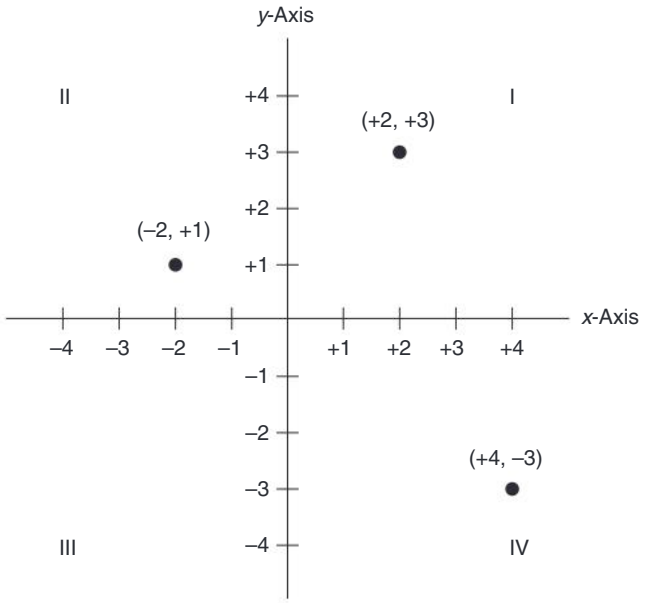


Figure 11.3 The Cartesian coordinate system allows the specific, repeatable localization of points in space. The *x*- and *y*-axes divide an area into four quarters known as *quadrants*. The upper right-hand quadrant is termed the *first quadrant*, or *quadrant I*. *Quadrant II* is the upper left quadrant, *quadrant III* is the lower left quadrant, and *quadrant IV* is the lower right quadrant.

If any one of these three angles is a 90-degree angle, the triangle is known as a *right triangle* (Figure 11.4). It obtains its name from the angle itself since 90-degree angles are known as *right angles*. The side of the triangle *opposite* the right angle is called the *hypotenuse*. If one of the angles of a triangle is 90 degrees, it logically follows that the sum of the two remaining angles must be 90 degrees.

In any right triangle, there is a certain relationship that exists between the lengths of each of the sides. This relationship states that, *for a right triangle, the length of the hypotenuse squared is equal to the sum of the squares of the remaining two sides*. This relationship is referred to as the *Pythagorean theorem* (Figure 11.5) and may be abbreviated as $a^2 + b^2 = c^2$, where c is the length of the hypotenuse and a and b the lengths of the two remaining sides.

Triangles even more specific in shape than the right triangle can have more specific established relationships between their sides. For example, a triangle whose angles are 45 degrees, 45 degrees, and 90 degrees has two sides of equal length. If each of these sides is taken as being 1 unit long, then the hypotenuse will be $\sqrt{2}$ units long (Figure 11.6). This follows from the Pythagorean theorem. (If this triangle occurs, algebraic equalities may be used to simplify solutions to a given problem.)

Another triangle with specific side-length relationships is the 30-degree, 60-degree, and 90-degree triangle. In this case, if the shortest side is taken as 1 unit of length, the second side will be $\sqrt{3}$ units, and the hypotenuse will be 2 units (Figure 11.7).

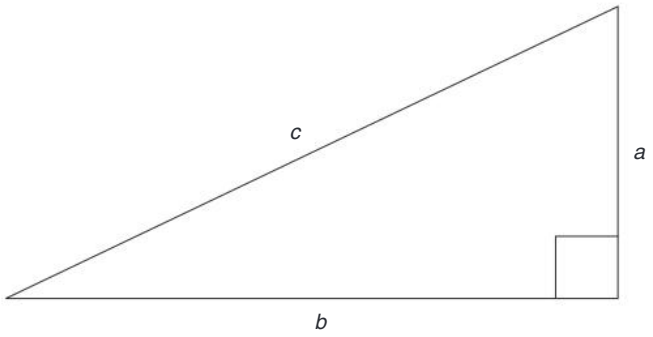


Figure 11.5 The Pythagorean theorem states that $a^2 + b^2 = c^2$. This theorem is valid only for right triangles.

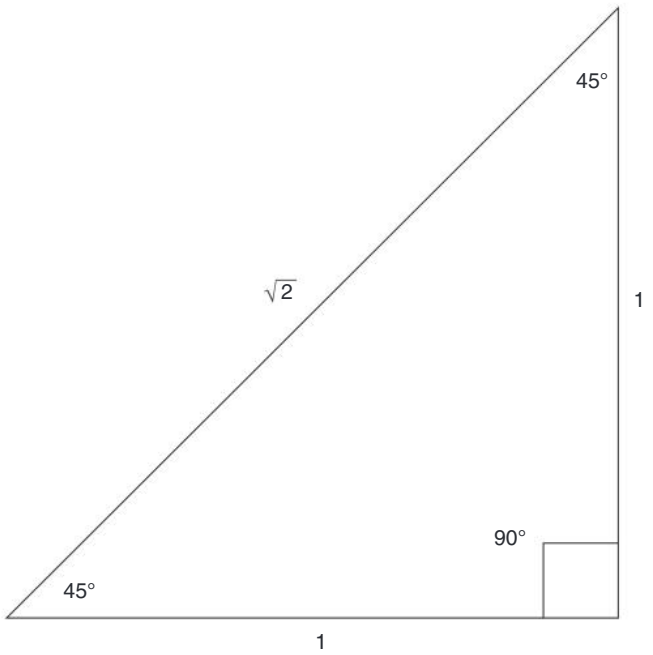


Figure 11.6 The relationship between the lengths of the sides for a 45-degree, 45-degree, and 90-degree triangle.

Similar Triangles

When two triangles have exactly the same shape but different sizes, they are said to be *similar triangles*. Similar triangles have (1) corresponding angles that are equal and (2) corresponding sides that are proportional in size (Figure 11.8). This corresponding size relationship helps considerably in finding unknown linear measurements when other corresponding measures in a similar geometrical configuration are known. Simple algebraic equalities may be used to find these unknown dimensions using side-length relationships of:

$$\frac{a}{a'} = \frac{b}{b'} = \frac{c}{c'}$$

(See Figure 11.8.)

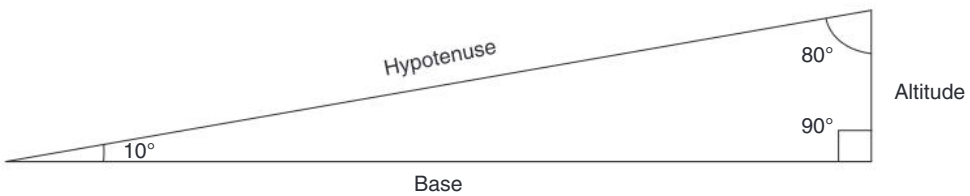


Figure 11.4 A right triangle contains one angle that is 90 degrees.

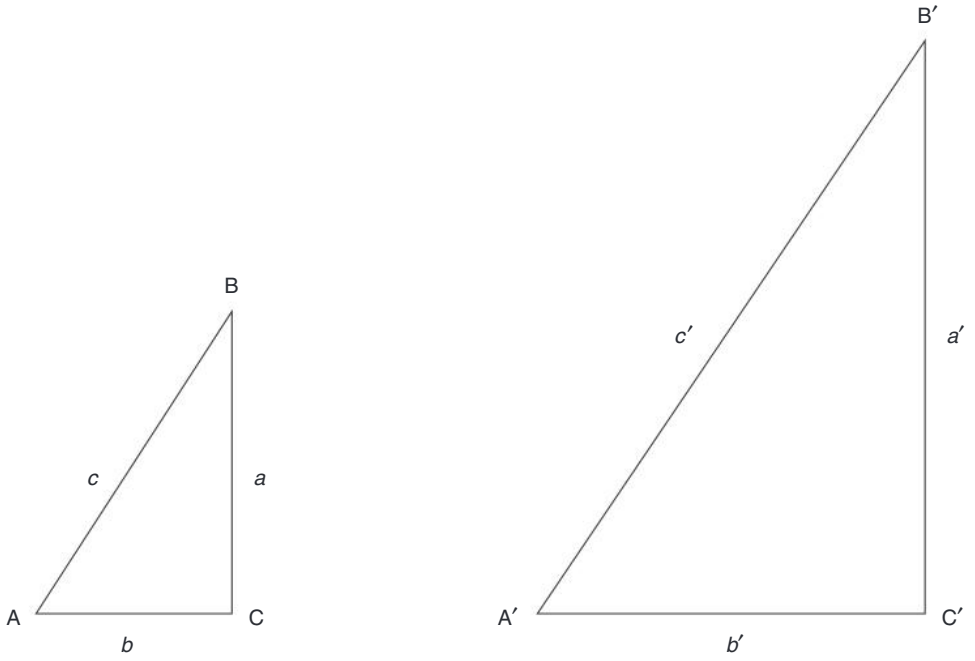


Figure 11.8 Similar triangles facilitate calculation of unknown dimensions from those which are already known. Capital letters represent angular measures; small letters stand for side lengths. In similar triangles, angles A and A′ are equal, B and B′ are equal, and C and C′ are equal.

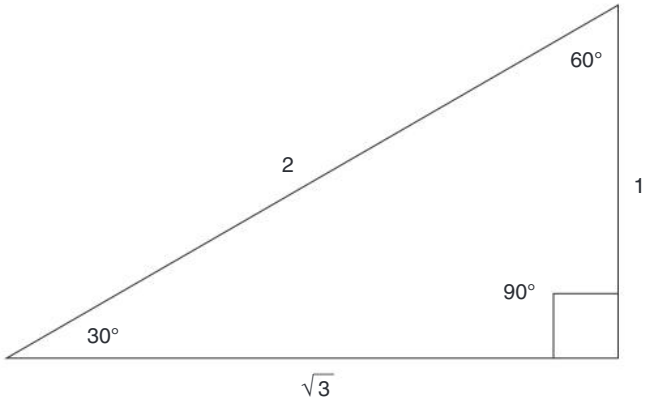


Figure 11.7 The relationship between the lengths of the sides for a 30-degree, 60-degree, and 90-degree triangle.

Example 11.1

If a vertical stick protruding 0.80 m out of the ground casts a shadow 0.30 m long, how high is a flagpole nearby that casts a shadow 5 m long?

Solution

Referring to Figure 11.8, a corresponds to the 0.80-m stick, b to the 0.30-m shadow. The 5-m flagpole shadow corresponds to b' and the unknown height of the flagpole to a'.

In other words,

$$a = 0.80\,\text{m}$$
$$b = 0.30\,\text{m}$$
$$b' = 5\,\text{m}$$

since

$$\frac{a}{a'} = \frac{b}{b'}$$
$$\frac{0.80}{a'} = \frac{0.30}{5}$$
$$0.80 = \frac{(0.30)\cdot a'}{5}$$
$$\frac{(0.80)(5)}{0.30} = a'$$
$$a' = 13.33\,\text{m}$$

This means that the flagpole is $13\frac{1}{3}$ m high.

REVIEW OF TRIGONOMETRY

The section on geometry demonstrated how unknown length dimensions can be found when one dimension of a triangle is known along with the dimensions of a similarly shaped triangle.

This can also be done when only one dimension of a triangle is known by using the angular measures of the triangle. This method uses *trigonometry*.

If the specific angles of a given triangle are known, it is possible to predict the ratio of any two sides of a triangle using a concept of similar right triangles. One can determine unknown dimensions of a triangle through the use of these predetermined ratios, which are known as *trigonometric functions*.

For a given angle of a triangle, there are three main ratios of importance. In Figure 11.9, if angle A is the angle being used, then the ratio of

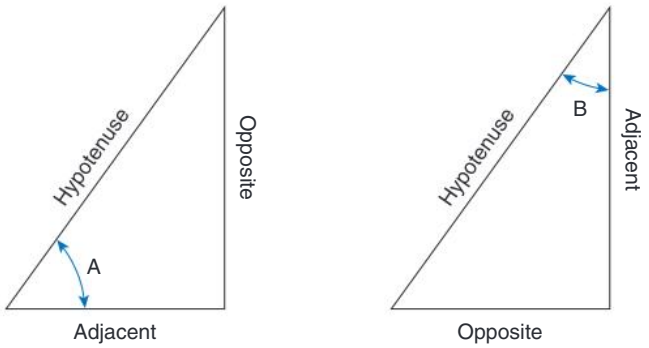


Figure 11.9 Although the position of the hypotenuse remains constant, the sides termed *opposite* and *adjacent* vary as to which of the angles is being referred.

$$\frac{\text{The side opposite angle A}}{\text{hypotenuse}} = \text{the sine of angle A}$$

The ratio of:

$$\frac{\text{The side adjacent to angle A}}{\text{hypotenuse}} = \text{the cosine of angle A}$$

And the ratio of:

$$\frac{\text{The side opposite angle A}}{\text{the side adjacent to angle A}} = \text{the tangent of angle A}$$

These are abbreviated more commonly as:

$$\sin A = \frac{\text{opp}}{\text{hyp}}$$

$$\cos A = \frac{\text{adj}}{\text{hyp}}$$

$$\tan A = \frac{\text{opp}}{\text{adj}}$$

Sine, cosine, and tangent ratios are found by using a calculator preprogrammed for these functions.

Example 11.2

The image of an object 6 m away from a prism is displaced upward 10 degrees by that prism. How far above the original position does the image now appear to be? (Figure 11.10 shows this situation.)

Solution

The ratio used for the 10-degree angle must include the known dimension and the dimension that needs to be calculated. In this case, the needed dimension is that which is *opposite* the 10-degree angle, and the known dimension is the one *adjacent* to the angle. The proper trigonometric function must contain both of these sides. The function containing both opposite and adjacent sides is the tangent of the angle.

Therefore, if:

$$\tan \angle = \frac{\text{opp}}{\text{adj}}$$

then

$$\tan 10 \text{ degrees} = \frac{\text{opp}}{6}$$

A calculator tells us that the tangent of 10 degrees is 0.17632. This means that:

$$0.17632 = \frac{\text{opp}}{6}$$

Using algebraic transformation,

$$\text{opp} = (0.17632)(6)$$
$$= 1.06 \text{ m}$$

This indicates that the prism displaces the image 1.06 m from its original position.

Vector Analysis

A *vector* is a mathematical quantity that conveys both magnitude and direction. It may be represented by a line of a given length pointing in a specific angular direction. Vectors are both additive and subtractive. Two vectors can combine to produce a resultant *vector sum,* which

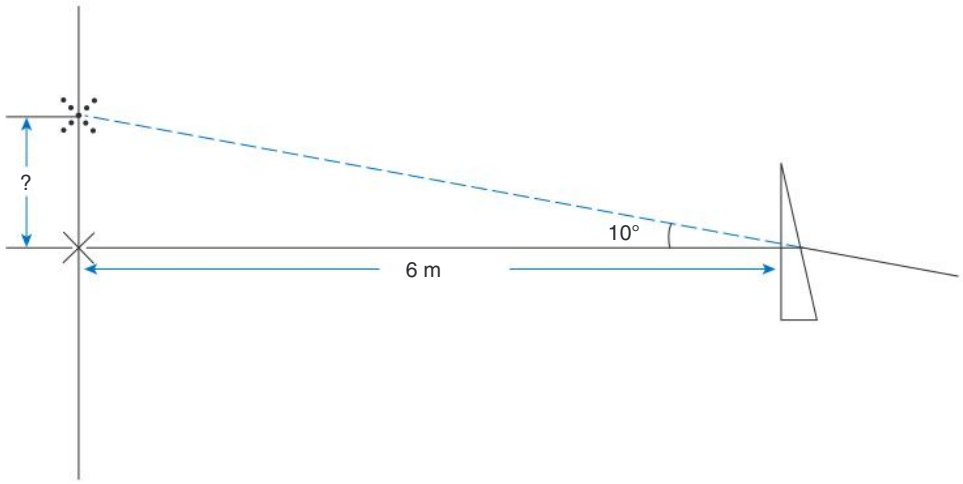


Figure 11.10 How far is the image displaced by the prism?

may be different from the two original vectors in both magnitude and direction. For example, a tractor pulls northward on an object with a force of 300 lb (Figure 11.11, *A*). A second tractor is hooked to the same object and also pulls in the same northward direction with a force of 300 lb (see Figure 11.11, *B*). The sum total of pull is 600 lb northward. This can be found with vector analysis by placing the second vector on the first, "tail-to-head" (see Figure 11.11, *C*). If drawn to scale, the measured sum of the two vectors gives the resultant vector sum. If the second tractor were pulling south, however, the resultant directional force would be zero. This time when the second vector is placed "tail-to-head" on the first, the head of the second ends up back on the starting point, indicating no net resultant force (see Figure 11.11, *D* and *E*).

Thus far, the forces have been either entirely complimentary to one another or completely opposing one another. When the vector forces are related to each other at angles other than 0 or 180 degrees, results are somewhat different. To illustrate, if one of these tractors were now pulling northeast and the other northwest, there is a cumulative effect of the two, but it is not as great as if both were pulling in the same direction. (On a 360-degree scale, one of the tractors would be pulling at 45 degrees and the other at 135 degrees.) Vector analysis can be done by again placing the second vector "tail-to-head" on the first, leaving its angular direction unchanged (Figure 11.12). If the two forces are carefully drawn to scale and their angular directions maintained, the resultant vector can be obtained by measurement. In this example, the vector sum is 424 lb of force being exerted in a northward, or 90-degree, direction.

Another way of thinking of vector analysis is in terms of "completing a parallelogram." A *parallelogram* is a four-sided geometrical figure with opposing sides parallel. Two vectors originating at the same point become the first half of a parallelogram, and it is then completed by drawing in the two missing sides parallel to those already present (Figure 11.13). The vector sum is the diagonal of the parallelogram drawn from the point of origin to the opposite corner.

The solution procedure just described has been *graphical* in that the vectors are often drawn on a graph to aid in accuracy. It is possible to use trigonometric functions to obtain more accurate results.

Vector analysis may be used in optics to determine the sum of two crossed prisms or two obliquely crossed cylinders.

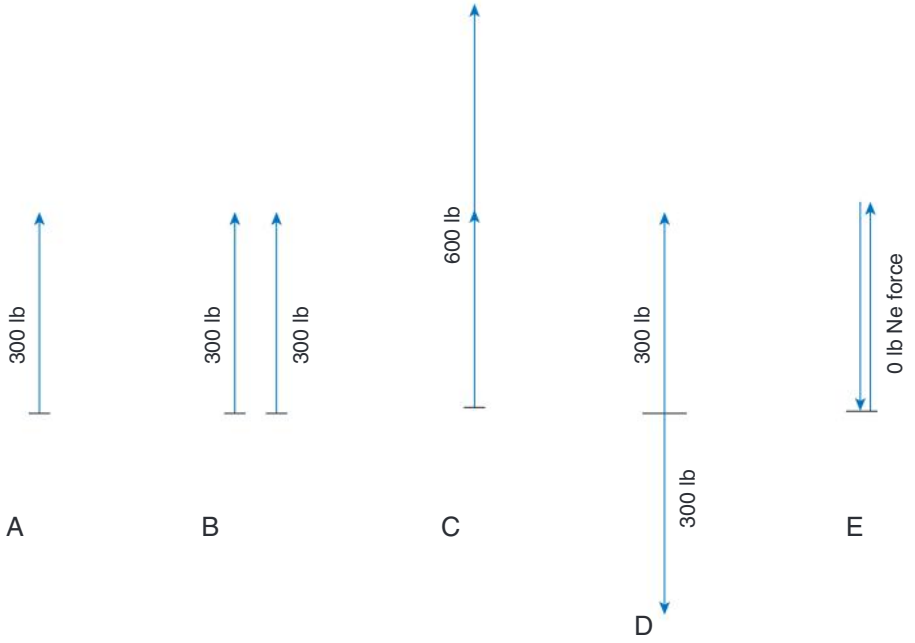


Figure 11.11 Vector analysis is the net sum of forces. **A** represents a tractor pulling northward with a force of 300 lb. The two forces **B** result in the vector sum **C**. If two equal forces pull in opposite directions **D**, when the vectors are plotted "tail-to-head," the head of the second arrow returns again to zero, showing no net force **E**.

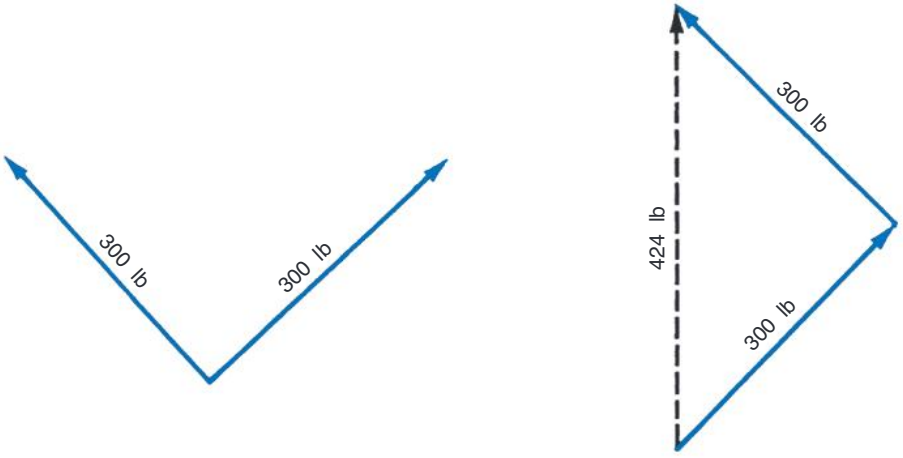


Figure 11.12 When forces are exerted in nonparallel directions, the principle of plotting these forces as "tail-to-head" may yet be used. The result is a straight line from origin to endpoint.

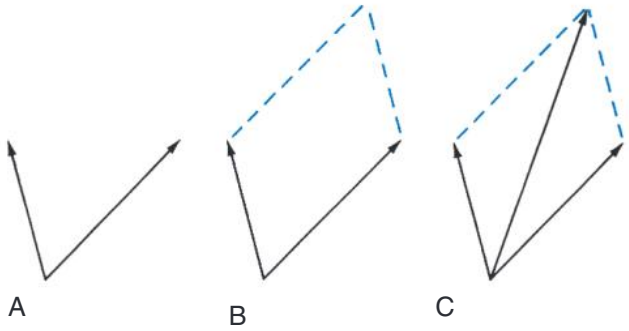


Figure 11.13 **A**, A representative pair of vector forces. Instead of plotting these vectors "tail-to-head," it is possible to realize their sums by using them to complete a parallelogram **(B)**. The resultant vector may now be drawn from the point of origin to the opposite corner of the parallelogram **(C)**.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. How many centimeters are there in a meter?
   - **a.** 12
   - **b.** 10
   - **c.** 100
   - **d.** 1000
   - **e.** 0.01
2. The basic metric unit of weight is the:
   - **a.** meter.
   - **b.** centimeter.
   - **c.** cubic centimeter.
   - **d.** gram.
   - **e.** pound.
3. In mathematical transformations, if a complete component is moved across the equal sign to the other side of the equation:
   - **a.** the number is squared.
   - **b.** the number will always become a negative number.
   - **c.** the sign of the number is changed.
   - **d.** the operation cannot be performed.
   - **e.** the operation is possible but not as described in any of the answers above.
4. The opposite of -4 is:
   - **a.** -4.
   - **b.** Zero.
   - **c.** $+4$.
   - **d.** $-(-4)$.
   - **e.** both c and d are correct.
5. Here is an equation. Solve for the unknown value a:

$$a = \frac{(3) \times (7)}{4 - 1}$$

   - **a.** 3
   - **b.** 3.33
   - **c.** 4
   - **d.** 5.25
   - **e.** 7
6. Solve for a:

$$a = (3 + 7) \times (4 - 2)$$

   - **a.** 60
   - **b.** 42
   - **c.** 29
   - **d.** 20
   - **e.** 8
7. Solve for a:

$$a = \frac{(4 \times 9) + 2}{8}$$

   - **a.** 38
   - **b.** 7
   - **c.** 5.5
   - **d.** 4.75
   - **e.** 1.875
8. Solve for a:

$$5 = \frac{a + 4}{3}$$

   - **a.** 0.267
   - **b.** 3
   - **c.** 3.75
   - **d.** 11
   - **e.** 19
9. Solve for a:

$$7 = \frac{(7 \times 3 + 2)}{a}$$

   - **a.** 0.30
   - **b.** 3.29
   - **c.** 5
   - **d.** 35
   - **e.** 245
10. Solve for a:

$$b = \frac{(4 \times a) - 3}{4}$$

   - **a.** $\frac{(4 \times b) - 3}{4}$
   - **b.** $\frac{4b + 3}{4}$
   - **c.** $\frac{4b - 3}{4}$
   - **d.** $4b + 3$
   - **e.** $4b + 3$

11. Solve for a:

$$4 = \frac{ab}{(3 + 2b)}$$

a. $\frac{12 + 8b}{b}$
b. 20
c. $\frac{4b}{(3 + 2b)}$
d. $\frac{12 + 2b}{b}$

12. Solve for a:

$$c = \frac{4b - a}{2b}$$

a. $\frac{2b + c}{4b}$
b. $2bc - 4b$
c. $4b + 2bc$
d. $4b - 2bc$

13. Which of the following is ***not*** equal to $2(a + a)$?
a. $2a + 2a$
b. $2a^2$
c. $(2 + 2)a$
d. $4a$
e. All of the above are the same as $2(a + a)$.

14. If we know the focal length of a lens (f), we may find the dioptric power of the lens (D) by finding the reciprocal of the focal length in meters. If a lens has a focal length of +20 cm, what is the dioptric power of the lens?
a. +0.20 D
b. +0.05 D
c. +0.50 D
d. +2.00 D
e. +5.00 D

15. If a lens has a focal length of −40 cm, what is the dioptric power of the lens? (If the focal length of a lens is a minus number, the focal point is to the left of the lens. The lens is the zero point. By convention, light is shown as traveling from left to right.)
a. −0.40 D
b. −0.04 D
c. −0.25 D
d. −2.50 D
e. −4.00 D

16. If a lens has a dioptric power of −3.00 D, what is the focal length of the lens?
a. −0.03 m or −3 cm
b. −0.33 m or −33.3 cm
c. −3 m or −300 cm
d. −3.33 m or −333 cm

17. When considering the amount of light that is reflected from the surface of a lens, there is an equation called the Fresnel equation that states:

$$I_R = \left[\frac{n' - n}{n' + n}\right]^2 \times I$$

where
I_R=the amount of light reflected from the surface
n'=the index of the lens
n=the index of the medium surrounding the lens, which would be air
I=the amount of incident light, which in this case would be equal to 1, or all incident light

If the lens is made from CR-39 plastic of index of refraction 1.5 and air has a refractive index of 1, what is the amount of light reflected from the surface? The amount of incident light is equal to 1, or all incoming light. (Your answer will not be a percentage. To get the percentage of light reflected, you would need to multiply your answer by 100.)
a. 0.03
b. 0.04
c. 0.36
d. 0.40
e. 25

18. To find the ideal index of refraction for a single layer antireflection coating, we need to know the index of the lens upon which the coating, or film, is to be applied. The equation used will then fulfill the *amplitude condition*. That equation requires us to find the square root of the index of refraction of the lens material. That equation is:

$$n_{film} = \sqrt{n_{lens}}$$

If the lens has an index of refraction of 1.5, what is the index of the ideal coating or film to be applied to the lens to prevent unwanted lens reflection?
a. 1.22
b. 1.34
c. 1.50
d. 1.58
e. 2.25

19. Use similar triangles to solve this problem.
You are looking at a spot on the wall that is straight in front of you. The wall is 200 cm away. A base-up prism is placed in front of your eye. This causes the spot to appear to move 4 cm downward. If the wall was only 100 cm from you, how far downward would you expect the spot to move?
a. 8 cm
b. 4 cm
c. 2 cm
d. 1 cm

20. In the late afternoon, a 1-m tall stick casts a 1.36-m shadow. A nearby telephone pole also casts a shadow. That shadow is 22 m long. Using similar triangles, what is the height of the telephone pole?
a. 3.34 m
b. 33.42 m
c. 6.18 m
d. 16.18 m
e. 29.92 m

21. A board 3 m long is leaned against a wall. One end of the board is 50 cm from the wall. How high up the wall does the other end of the board reach? (Use the Pythagorean theorem to solve this problem.)
a. 3.04 m
b. 3.50 m
c. 2.50 m
d. 2.96 m
e. 7.65 m

22. A ladder is leaned against the side of a house at a 60-degree angle (measured from ground to ladder). The ladder is 4 m long. This forms a right triangle. Use trigonometry to first determine how far the base of the ladder is from the house. (This is the measure *adjacent* to the 60-degree angle.) Next, determine how high up the wall the ladder touches. (This is the measure *opposite* to the 60-degree angle.)
a. 2 m from the house and 3.46 m up the wall.
b. 0.8 m from the house and 3.71 m up the wall.
c. 1.73 m from the house and 3.66 m up the wall.
d. 1.5 m from the house and 3.71 m up the wall.

23. When prism is prescribed, it can be either just horizontal prism (base-in or base-out), just vertical prism (base-up or base-down), or it can contain both horizontal and vertical prism, such as both base-up and base-out. When horizontal and vertical prism are both used at the same time on the same eye, they combine to form one prism found at an oblique angle between the horizontal and vertical components. The amount of oblique prism and the angle of the base direction of the oblique prism may be found when the horizontal and vertical components are known. The horizontal and vertical components are like two sides of a right triangle. The resulting oblique prism is like the hypotenuse of a right triangle.

There is both base-in horizontal and base-up vertical prism prescribed for the right eye. The base-in prism has a prism power of 4 Δ. The base-up prism has a power of 2 Δ. When this is drawn, it will appear much like what is shown in Figure 11.7 but with different numbers. What would be the power of the resulting oblique prism? (In other words, what would the value of the length of the hypotenuse of this triangle be?)
a. 2.45 Δ
b. 4.47 Δ
c. 5 Δ
d. 6 Δ
e. 20 Δ

24. For the above problem, what would be the angle of the resulting prism in degrees produced by the combined horizontal and vertical prisms? Find your answer using trigonometry.
a. 0.01 degree
b. 26.57 degrees
c. 30.00 degrees
d. 60.00 degrees
e. 63.43 degrees

25. Which of the following is *not* a parallelogram?
a. square
b. rectangle
c. triangle
d. diamond

12

Characteristics of Ophthalmic Lenses

THEORY OF LIGHT

To understand the way light behaves for lenses, we need to look at the nature of light itself. In simplistic terms, when light travels, it behaves in two ways:

1. Like a wave generated by dropping a rock into a pond (Figure 12.1).
2. Like a particle or photon. This could be compared with a controlled and continuing "explosion" of light that might be visualized in Figure 12.2.

For our purposes, we can best understand light as a wave.

Defining Light Waves

A light wave has certain characteristics as shown in Figure 12.3. The highest part of the wave is called the *crest,* and the lowest, the *trough*. The vertical distance from the trough to the crest is called the *amplitude*. The greater the amplitude is, the greater the intensity of the light. The horizontal distance from one crest to the next is called the *wavelength*. As wavelength changes, so does the perceived color of the light.

The Visible Spectrum

The wavelengths of light that are visible to the human eye vary in length from 380 to 760 nm. These are only a small part of what is called the *electromagnetic spectrum.* The electromagnetic spectrum goes from very short cosmic, or gamma, rays to extremely long radio waves (Figure 12.4).

When the sun radiates visible light, it includes the entire visible spectrum. When we see the whole spectrum of visible wavelengths together, we perceive the light as being white; when we see only one wavelength of light or several wavelengths that are very close to one another in length, we see that light as one specific color.

Colored Light

When white light is broken up into its component colors, it has a specific order of colors. Those colors of the rainbow were memorized by most people in elementary school by using the acronym for the imaginary name "Roy G. Biv" (Figure 12.5). The letters refer to the colors red, orange, yellow, green, blue, indigo, and violet. In optics, we order colored light according to wavelength, starting with the shortest and going to the longest. The shortest visible wavelength is blue, and the longest is red. Therefore, we need to consider the "Roy G. Biv" acronym as being spelled backward (vib g yor).

Technically, each wavelength has its own color. However, the changes in color from one wavelength to the next are so small that we can only discriminate in wavelength areas. Figure 12.6. shows approximate wavelengths and their associated colors. Interestingly enough, different cultures make the color break at different places. For example, at the border between blue and purple, some cultures will identify that "in-between" wavelength area as blue, whereas another will call it purple.

A luminous or primary source is one that generates light. A candle would be an example of a primary source of light. The color of such an object depends on the wavelength(s) of light that the luminous source generates.

A secondary source of light is one that is reflecting light from a primary source. The moon is a secondary source of light. The color of a secondary source of light depends on what wavelengths it is reflecting. A white shirt reflects all wavelengths of light. A blue shirt reflects only blue light and absorbs all other wavelengths. A black shirt absorbs all wavelengths of light. With this in mind, it is understandable why white shirts are cooler on hot, sunny days than black shirts.

For more on the visible spectrum, including ultraviolet and infrared radiation, see Chapter 22.

REFLECTION

Unless interrupted, a single ray of light travels in a straight line. Placing a highly reflective object in its path causes the light to bounce back at an angle. This type of reflection is called *regular* or *specular reflection* (Figure 12.7). The angle at which the light strikes the surface is known as the *angle of incidence* (Figure 12.8). It is measured from a line perpendicular to the reflecting surface at the point of reflection known as the *normal* to the surface. The angle at which the ray is reflected is known as the *angle of reflection*. This also is measured from the normal.

The angle at which the light is reflected is predictable if the angle at which it strikes the surface is known since the *angle of incidence (i) is always equal to the angle of reflection (r).*

When light strikes matte or dull (irregular) surfaces, it is still reflected, but variable scattering of the light rays occurs. This type of reflection is called *diffuse reflection* (Figure 12.9).

THE SPEED OF LIGHT AND REFRACTIVE INDEX

Light is able to travel faster through some materials than through others. Simply stated, some materials have more resistance to the speed of light than others. There is no resistance to light in a vacuum because there is nothing in a vacuum. Light travels at its maximum speed of about 186,355 miles/s (or 299,792,458 m/s) in a vacuum. However, when light enters a clear medium, such as water, there is resistance, and the speed of light slows. The medium of less resistance (such as air) is said to be the *rarer* medium. The medium of more resistance is said to be the *denser* medium.

The amount of resistance to the speed of light that slows it down is represented by a number. This number is referred to as the *refractive index*. The more the material slows the passage of light, the higher is its refractive index.

The number for the refractive index of a given substance is obtained by comparing the speed of light in a vacuum with the speed of light in the new substance. It is written as a fraction. The speed of light in a vacuum is

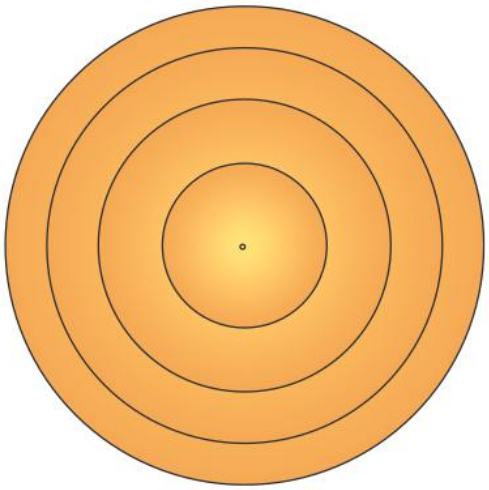


Figure 12.1 Light can be thought of as traveling away from its point of origin in waves, much like what happens when an object is thrown into a smooth pond, causing a wave to travel outward.

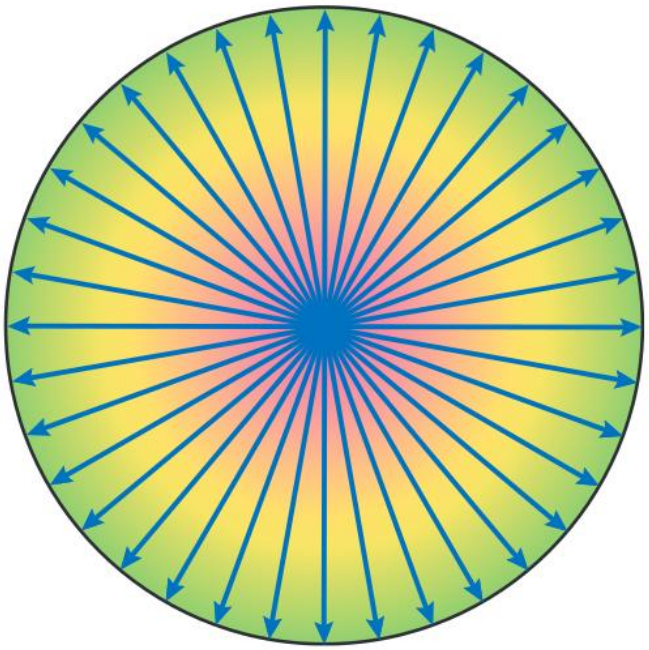


Figure 12.2 Light can also be thought of as particles of energy, called *photons*, leaving the source.

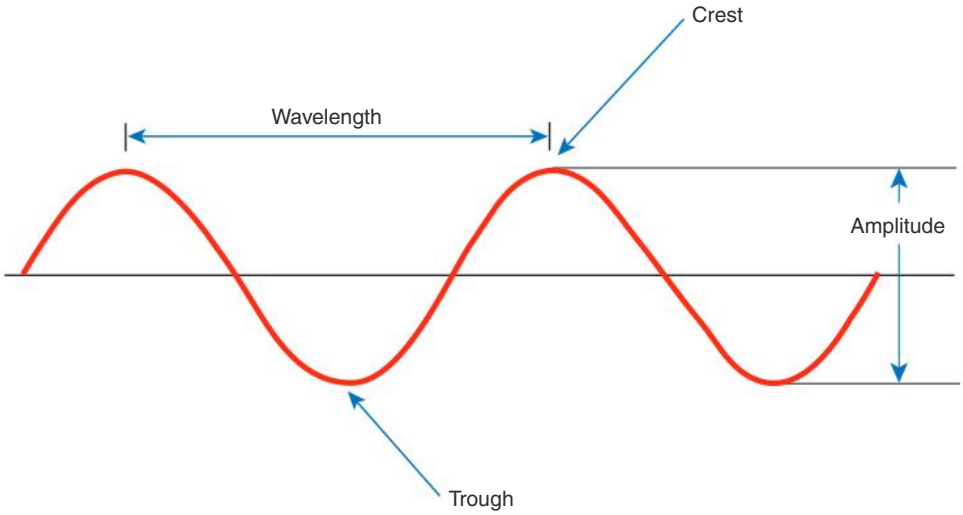


Figure 12.3 Light waves have crests and troughs, with a wavelength being measured from crest to crest.

on top (the numerator) and the reduced speed of light in the new substance on the bottom (the denominator). The speed in the denominator is always the slower speed and smaller number; thus the fraction will always come out greater than 1. Here is how it is written:

$$\frac{\text{Speed of light in a vacuum}}{\text{Speed of light in new substance}} = \text{Absolute refractive index}$$

Because there cannot be less resistance to the speed of light than nothing at all (a vacuum), this number for the refractive index is called the *absolute refractive index.*

However, we live on earth where almost everything is surrounded by air. Since light travels almost as fast in air as in a vacuum, we use air instead of a vacuum as the standard when calculating refractive index. Since the value for refractive index obtained is relative to air instead of to a vacuum, the refractive index obtained in this manner is called the *relative refractive index.* This is expressed as the fraction:

$$\frac{\text{Speed of light in air}}{\text{Speed of light in new substance}} = \text{Relative refractive index}$$

Refractive index is commonly abbreviated as *n,* and the number we use when speaking of refractive index refers to relative refractive index.

Refractive Index Is Wavelength Specific[1]

Wavelengths increase in length across the visible spectrum going from the blue to the red end. We say that a given material has a certain refractive index. However, that is not entirely true. Since each wavelength travels through a transparent material at a slightly different speed, each wavelength (think color) has a slightly different refractive index. So when we say that a certain material like polycarbonate has a certain refractive index, we are basing that on a certain yellow wavelength in the middle of the visible spectrum. The United States uses the

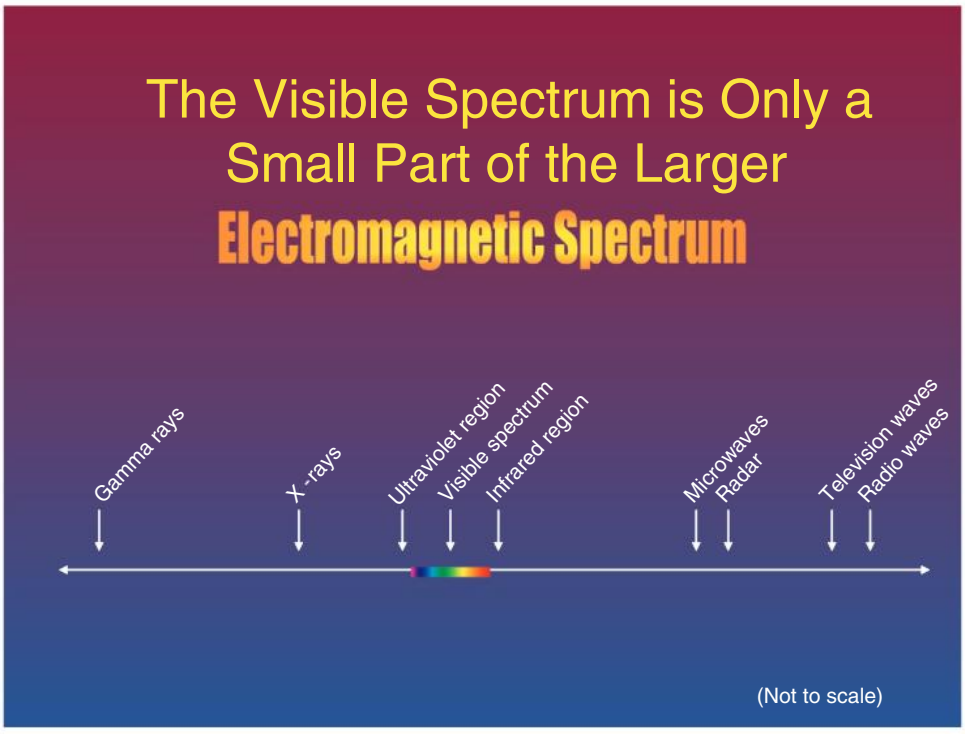


Figure 12.4 Visible light is only a small part of the larger electromagnetic spectrum that includes everything from very short gamma rays to extremely long radio waves.

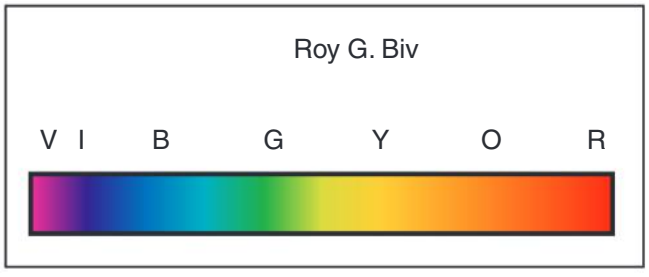


Figure 12.5 When we consider light, we generally go from left to right, starting with the shortest violet wavelengths and ending with the longer red wavelengths. So, when looking at the order of the colors, the traditional acronym of the fictitious name, "Roy G. Biv," will be spelled backward.

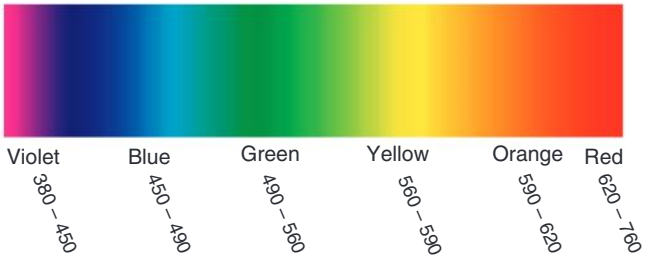


Figure 12.6 How color and wavelength correspond.

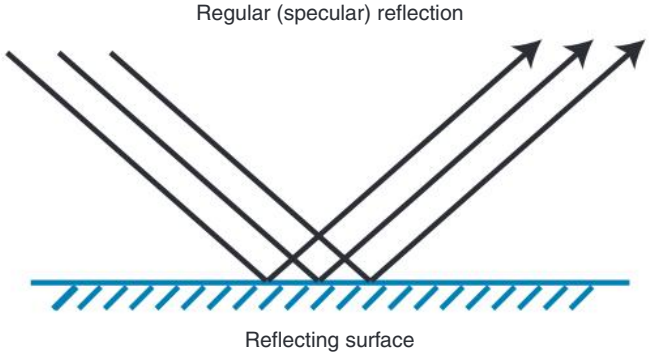


Figure 12.7 Specular or regular reflection occurs with a smooth surface.

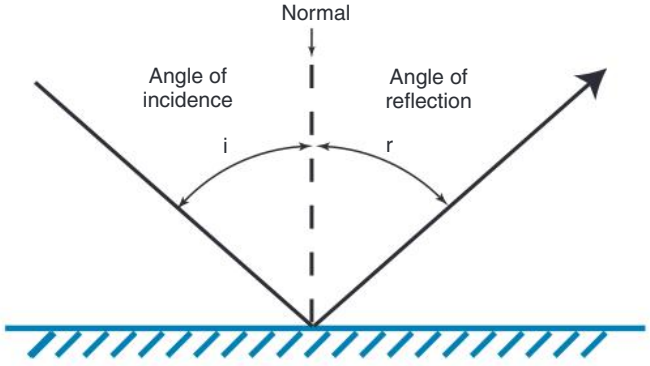


Figure 12.8 For reflected light, the angle of reflection always equals the angle of incidence. Both angles are measured from a line perpendicular to the reflecting surface known as the normal. *i*, Angle of incidence; *r*, angle of reflection.

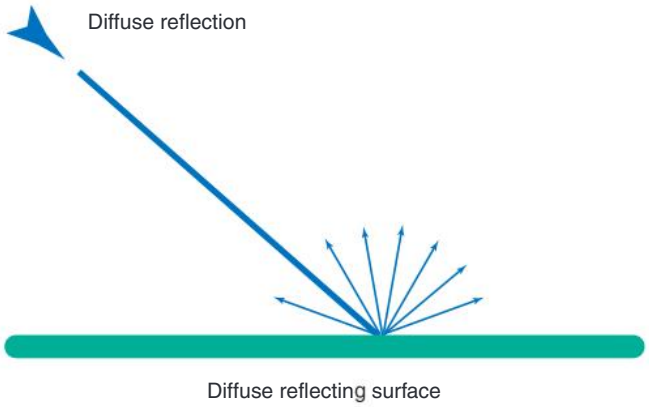


Figure 12.9 Diffuse reflection occurs when light strikes a surface that is matte or irregular.

so-called helium d line (587.56 nm). Using the helium d line results in an index of refraction for polycarbonate of 1.586. However, Europe and Asia use what is called the *mercury e-line* (546.07 nm). This wavelength results in an index of 1.590 for the same polycarbonate material. This doesn't seem like much of a difference, but when lens powers are high, the same lens will have two different powers that are slightly different. Lens-measuring instruments like lensmeters are calibrated for one or the other of these wavelengths (although some instruments allow the operator to choose which one to use).

A lens material may sometimes be listed as having one refractive index, and then somewhere else it may be listed as having a different index. This can be confusing. Just remember, it all depends on which reference wavelength is being used.

REFRACTION

When light strikes a new, transparent medium straight on (at a 90-degree angle, perpendicular to the surface), the light slows down but continues in the same direction.

But when light strikes a new substance or medium at an angle, the change in speed in the new medium causes the light to change direction. Consider the case of light passing from a low refractive index medium such as air to a higher refractive index medium such as water or even glass. To understand what is happening and why, consider the analogy of a car traveling on a smooth substance with little resistance, such as a smooth, paved road. In a moment of driver inattention, the car drifts to the side and encounters a rough surface, such as the gravel shoulder of the road. When the right wheel hits the rough gravel, in which direction does the car want to go? Because the right side of the car slows faster than the left side, the car pulls to the right.

When a light ray passes from a rarer medium (low refractive index) and strikes a denser medium at an angle, the light will be bent, or *refracted*. The direction of the refraction is toward the normal to the surface (Figure 12.10). Remember, the "normal" to the surface is a line perpendicular to the surface at the place where the light strikes the surface.

Snell's Law

If the refractive indices of both media through which light is traveling are known, the angle of refraction for a given angle of incidence is predictable. It may be calculated geometrically using the sines of the angles of incidence and refraction. It is expressed algebraically as:

$$n \sin i = n' \sin i'$$

This is known as *Snell's law*.

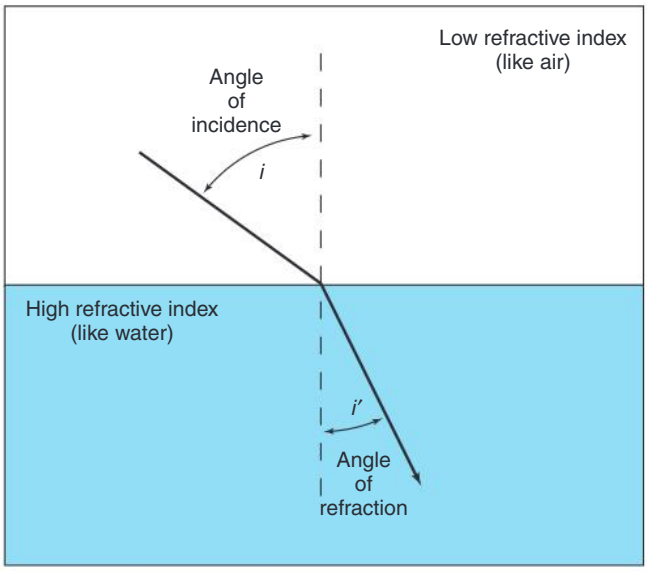


Figure 12.10 The figure shows the bending, or refraction, of light going from a rarer to a denser medium. To see how light is bent going from a denser to a rarer medium, simply turn the figure upside down and visualize it traveling in the opposite direction.

Example 12.1

Suppose a ray of light is traveling from air of refractive index 1 to glass of index 1.523. If the ray strikes the glass at an angle of 30 degrees, what will be the angle of refraction?

Solution

We know that:

$$n = 1 \text{ (refractive index of air)}$$
$$n' = 1.523 \text{ (refractive index of glass)}$$
$$i = 30 \text{ degrees (angle of incidence)}$$

But we do not know the angle of refraction.

$$i' = ? \text{(angle of refraction)}$$

If

$$n \sin i = n' \sin i',$$

then, for our example,

$$(1)(\sin 30) = (1.523)(\sin i')$$

Since sin i' is the unknown, the above formula can be rearranged algebraically as follows:

$$\frac{(1)(\sin 30)}{1.523} = (\sin i').$$

Using a calculator capable of generating trigonometric functions, it is found that

$$\sin 30 = 0.5.$$

Therefore,

$$\sin i' = \frac{(1)(0.5)}{1.523} = 0.3283.$$

Again, using a calculator, it is determined that 0.3283 is the sine of 19.2 degrees. This is done by finding the inverse sine of 0.3283. (The inverse sine is abbreviated as $\sin^{-1}$.) Thus, the resulting angle of refraction is 19.2 degrees.

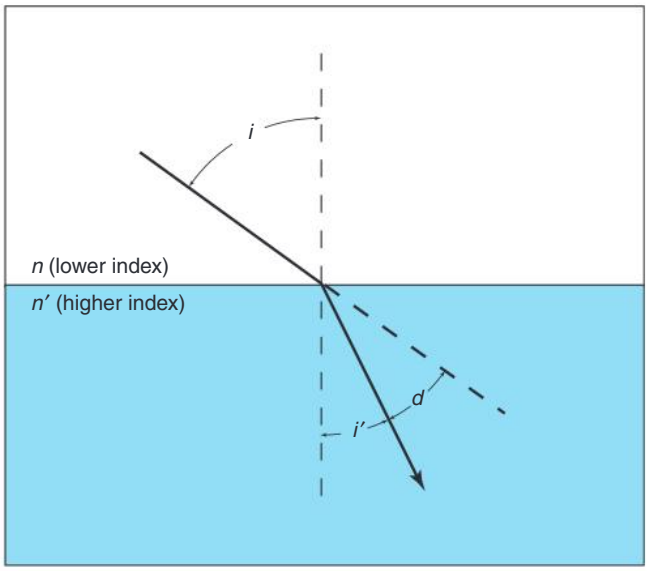


Figure 12.11 The angle of deviation is the angular change in light direction from its original path.

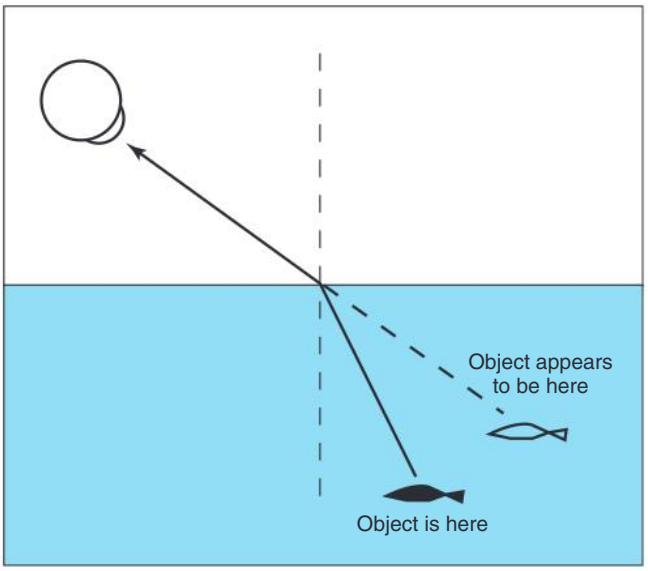


Figure 12.12 When light from an object in another medium, such as water, is seen at an angle, the light rays are bent, making the object appear to be somewhere other than its actual location.

Angle of Deviation

The angle of refraction is the angle of the refracted ray with reference to the normal. The angular amount that the light has deviated from its original path is called the *angle of deviation* (d) (Figure 12.11). It is not measured directly but is calculated.

It can be seen from the geometry of the figure that for light leaving a rare and entering a dense medium, $i = d + i'$. Therefore, the angle of deviation is $d = i - i'$.

Example 12.2

Example 12.1 asked for the angle of refraction for light entering a new medium at an angle of incidence of 30 degrees. The angle of refraction was found to be 19.2 degrees. Knowing this, what is the angle of deviation?

Solution

We know that the angle of deviation is

$$d = i - i'.$$

Since the angle of incidence (i) is 30 degrees and the angle of refraction (i') is 19.2 degrees, then

$$d = 30 - 19.2$$
$$= 10.8 \text{ degrees}.$$

The angle of deviation is calculated as $d = i - i'$ because light is leaving a rare medium and going into a dense one.

An example of light coming from a dense medium, like water, and traveling into a rare medium, like air, is shown in Figure 12.12. This figure helps to explain why objects that are viewed below the surface of water are not always where they appear to be. Attempts to spear the fish in Figure 12.12. would be unsuccessful unless the spear fisherman compensated for the apparent location of the fish.

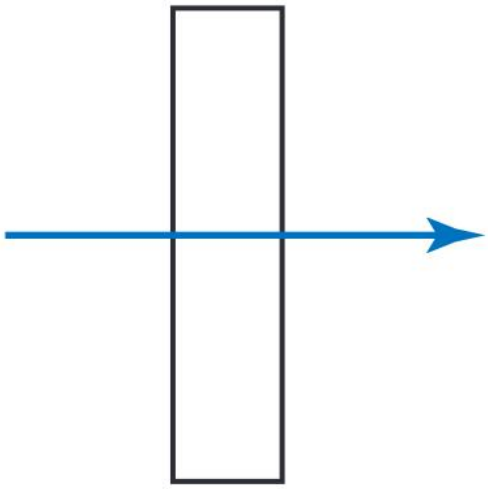


Figure 12.13 A ray of light entering a parallel-sided slab of glass perpendicular to both surfaces will pass through without ever changing direction.

PRISM

When Light Goes Straight Through Parallel Surfaces

When light leaves air and enters a slab of glass, the light travels more slowly in the glass. If the two sides of the glass slab are parallel and the light enters perpendicular to the front surface, it does not bend at all. It simply slows down. And when the ray of light strikes the back surface of the glass, it is still perpendicular to the surface and does not bend. It comes out the other side of the slab of glass unchanged in direction. The light leaves the other side of the glass at exactly the same 90-degree angle that it first entered (Figure 12.13). (Incidentally, when the light leaves the glass and goes back into air, it speeds back up to its original, expected speed in air.)

When Light Goes Through Parallel Surfaces at an Angle

If light strikes a parallel-surfaced slab of glass at an angle, the ray will be bent at each surface in accordance with the rule of refraction. Since the

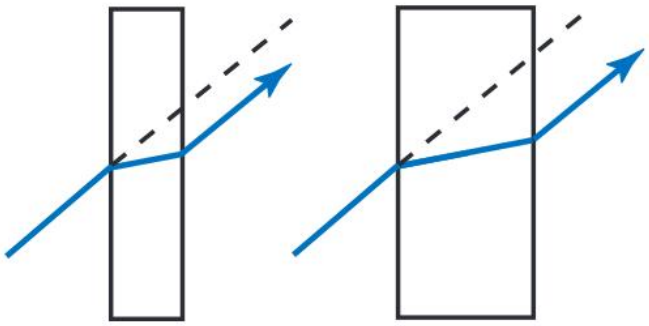


Figure 12.14 Light entering a parallel-sided slab of glass at an angle is bent at both front and back surfaces. If the media on both sides of the material are the same, as when the slab is surrounded by air, the ray of light will leave parallel to its original direction. Although traveling in exactly the same direction, the ray of light will be displaced laterally. The amount of displacement depends on the thickness of the slab.

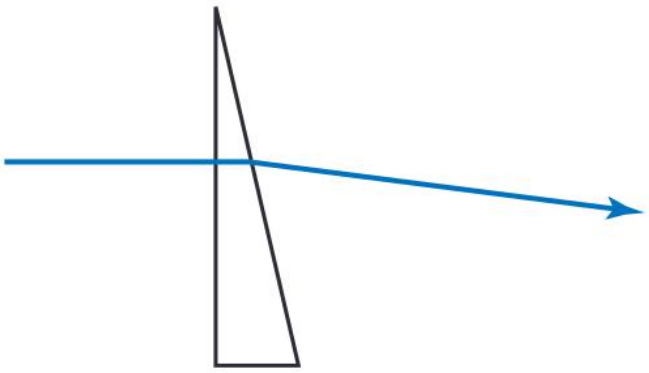


Figure 12.15 Here, light strikes the first surface straight on and is not bent until it reaches the second angled surface. Now it is bent and leaves in a different direction.

indices of the glass and of air at both surfaces are the same, the emergent ray and the incident ray will be parallel, just as when the ray struck the glass from straight ahead. The only difference is that it will be slightly displaced laterally. The amount of displacement depends on the angle at which the incident ray struck the glass and the thickness of the glass (Figure 12.14).

When the Two Surfaces Are Not Parallel

Suppose that the two surfaces of glass are not parallel to one another as shown in Figure 12.15. In this figure, a ray of light strikes the first surface straight on at a 90-degree angle. It is not bent from its original path. However, the second surface is at an angle to the first surface, giving the glass a prism shape.

The ray of light continues to pass through the glass and strikes the second (angled) surface at an angle. In this case, the angle that the light strikes the surface is equal to the angle of tilt of the second surface. Because the ray of light is going from a denser to a rarer medium, it will be bent away from the normal to the surface by an amount greater than its angle of incidence. This will cause the light to be bent downward toward the base of the prism. The amount of this deviation is predictable using Snell's law. *A ray of light is always bent toward the base of a prism.*

The tip of a prism is called the *apex*. The wider, bottom part of a prism is called the *base* (Figure 12.16).

More information on how prism works can be found in Chapters 15 and 16.

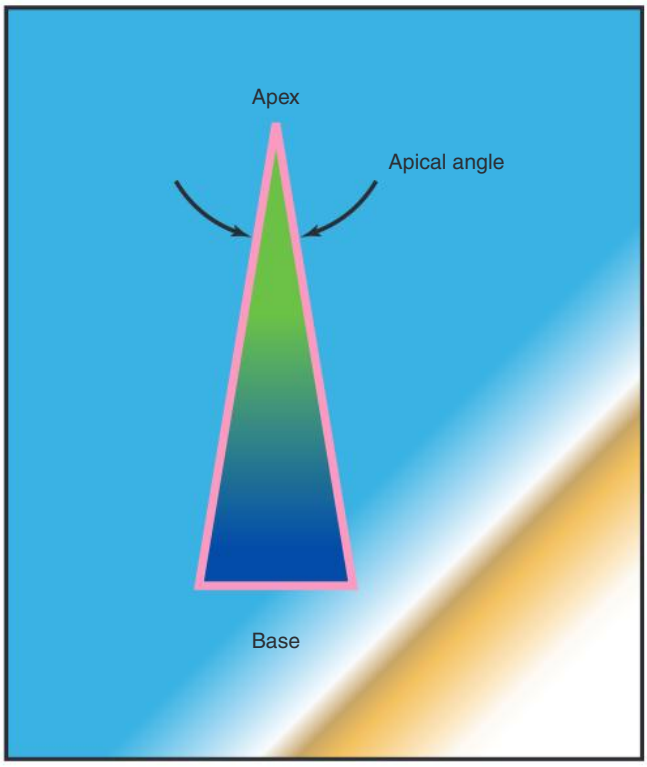


Figure 12.16 Basic prism terminology.

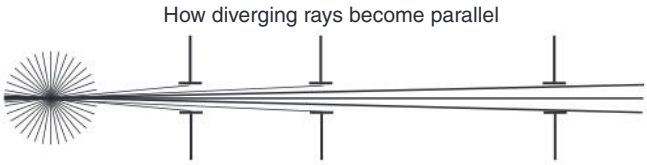


Figure 12.17 By looking at light passing through a series of apertures, it is easier to see that the farther from a source light rays travel, the less they diverge from one another. And the less they diverge from one another, the more parallel they become.

HOW CURVED LENSES REFRACT LIGHT

Refraction of Multiple Light Rays

Up to this point, we have seen how light acts when it is viewed as a single ray and strikes a flat surface. However, light does not come as a single ray but many, and lenses have curved surfaces instead of flat surfaces. With a curved refracting surface, multiple rays will all be either directed toward or away from a specific point in space.

Light rays emanate from a light source or object in an ever-increasing circle like the way a ripple goes out from the place where a stone is thrown into water. As these rays go out from their source, they are said to be *diverging*. The outer border of this ever-growing circle of light is called the *wave front*. The farther from the object source this wave front is, the less that light rays passing through an *aperture* or "hole" of a certain size will be diverging. The farther the rays are from the source, the more parallel to each other these neighboring rays become, as seen in Figure 12.17. After traveling far enough away from the object, these light rays no longer appear to be diverging. At an infinite distance from the object, they become parallel.

Focusing Light

Suppose it becomes desirable to divert parallel rays coming from an object at infinity to bring them to focus at one image point. If it were only a question of two parallel rays, the problem could be solved easily using principles explained earlier in the chapter. Since a prism deviates light at a known angle, if two prisms were placed base to base so as to interrupt these two rays, the rays could be caused to meet at a specified point known as the *focal point* (Figure 12.18). Rays traveling toward one specific point are said to be *converging*. In our example, the position of the focal point can be arbitrarily changed by merely increasing or decreasing the power of the two prisms.

If there were four parallel rays to be focused, however, the two-prism concept would no longer be feasible (Figure 12.19). Stronger prisms would be required to deviate the two outer rays enough to bring them to the same focal point. It would be possible to stretch this system by cutting off the tops of the original prisms and replacing the tops with prisms of stronger power (Figure 12.20). It quickly becomes obvious, however, that the more parallel rays there are, the more new prisms will be required.

Fortunately, the problem may be solved by creating a curved surface to replace the theoretical series of stacked prisms. The curve of the surface is in the form of an arc of a circle (Figure 12.21).

The shorter the radius of curvature, the more light is bent when striking the surface and consequently the closer to the lens the focal point will be.

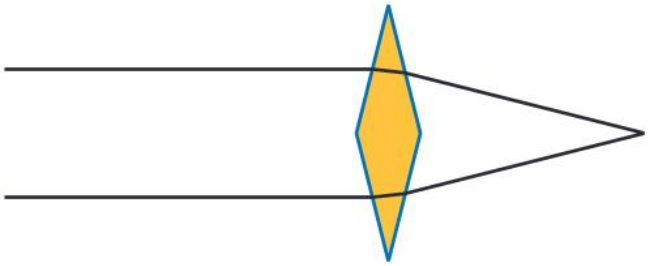


Figure 12.18 If only two parallel rays of light must be brought to a single point of focus, the job would be simple. Just use two prisms placed base to base.

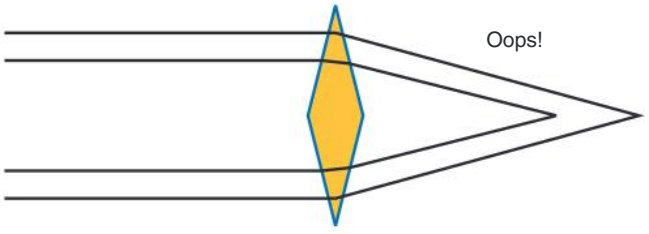


Figure 12.19 A two-prism system cannot be expected to bring light to a single point of focus if there are more than two rays of light.

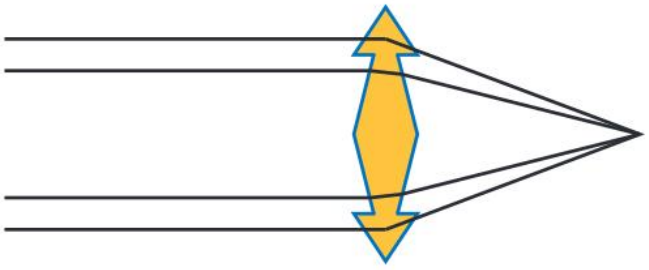


Figure 12.20 If just prisms were used to bring light to a focus, a different prism would be necessary for each incoming parallel ray to form a single point focus.

FOCAL POINTS AND DISTANCES

For a source at infinity, the specific point at which an image will be focused is known as the *second principal focus* (*F′*), or *secondary focal point*, of the lens. The distance from the lens to the secondary focal point is known as the *secondary focal length* of the lens (*f′*) (Figure 12.22).

The *first principal focus* (*F*), or *primary focal point*, of a lens is that point at which an object may be placed so that the lens will form an image of that object at infinity. In other words, the object is placed so that light rays *leaving* the lens are now parallel. The distance from the lens to the first principal focus is the *first* (or *primary*) *focal length* of the lens (Figure 12.23).

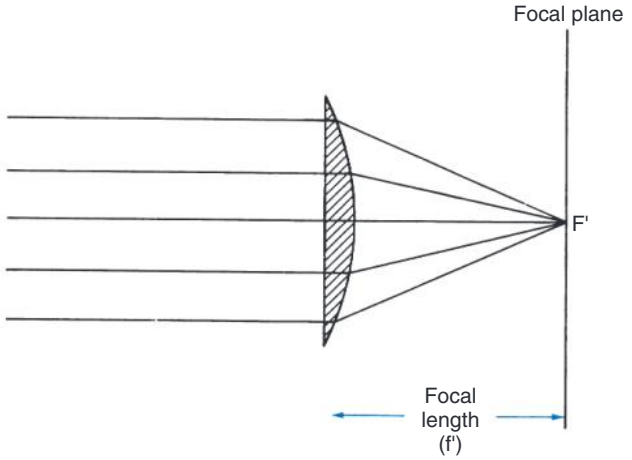


Figure 12.21 The point where parallel light entering a lens is brought to focus is known as the second principal focus of the lens. The distance from the center of the lens to this principal focus is the secondary focal length. In this figure, parallel light rays coming from an object at infinity converge to form a real image of the object. The lens is drawn with the front surface flat so that it is easier to see how the curved back surface has a changing angle. If a ray of light strikes the lens at the exact center, the curved back surface is flat and the light ray passes through without being bent. The farther toward the outside edge of the lens, the more the back surface will be angled. The more the back surface is angled, the more the incoming ray of light will be bent.

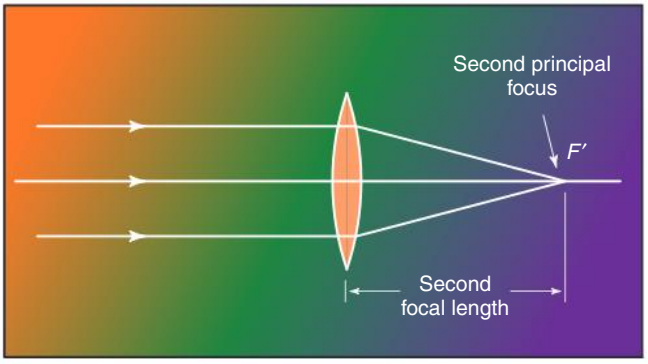


Figure 12.22 When parallel light enters the front surface of a lens, light is brought to a focus at what is called the *second principal focus*, or *secondary focal point*, of the lens.

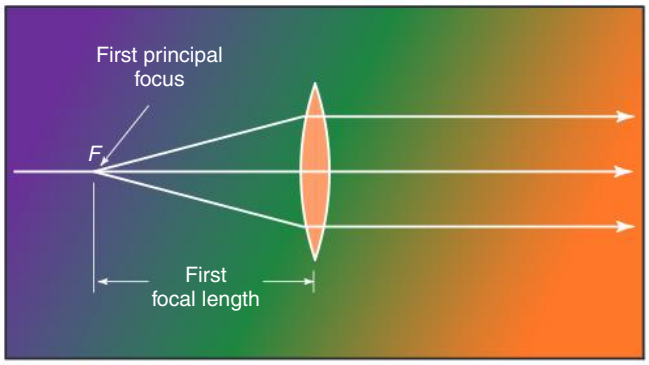


Figure 12.23 When an object is placed at the *first principal focus*, or *primary focal point*, of a lens, light rays will leave the lens parallel to one another.

For spectacle lenses, the more important focal point is the secondary focal point.

QUANTIFYING LENSES

Sign Convention

Up to this point, when prisms or lenses have been shown, the first surface has usually been a flat surface and perpendicular to the light. (In optics, a flat surface is called a *plano* surface.) All light entering the prism or lens has been parallel light. If the first surface is flat and perpendicular to the entering light, then light passes through the first surface undeviated (without being bent). It is not bent until it reaches the tilted or curved second surface. There has, therefore, been only one factor to consider: the second surface.

To have a common groundwork for understanding the action of a lens on other than parallel light and lenses with both surfaces curved, it is necessary to adhere to accepted conventions.

These *sign conventions* serve to prevent confusion and errors in describing the optics of lenses. Some of these conventions include the following:

1. Light is traditionally represented in optical drawings as traveling from left to right.
2. Any measurements are usually made with the lens at the center of the system—especially when the lens is a thin lens. It is as if the lens is at the zero point of a number line. All distances to the right of the lens are expressed as positive and all distances to the left as negative (Figure 12.24).
3. When measurements must be made anywhere other than left or right of the lens, all positions above a horizontal line passing through the lens center are considered positive; all positions below a horizontal line passing through the lens center are considered negative.
4. Lenses that cause parallel rays of light to converge are designated as having *plus* power, whereas those causing parallel rays of light to diverge are identified as being *minus*.

Surface Curvature

To enable the steepness of curvature of a surface to be quantified, a unit of measure based on the *radius of curvature* (r) has been chosen (Figure 12.25). So a surface can be quantified by its radius of curvature.

Convex and Concave Surfaces

Suppose the front surface of a lens or curved refracting surface has a radius of curvature of 20 cm. If the center of the radius of curvature is to the right, the radius of curvature is considered as being positive and the surface a convex surface (Figure 12.26).

If the radius of curvature of the front surface of a lens or curved refracting surface is centered to the left, the radius of curvature is considered as being negative and the surface a concave surface (Figure 12.27). For a lens in air, convex surfaces are positive (plus) in power, and concave surfaces are negative (minus).

Units of Lens Power

The power of a lens or lens surface to bend light is referred to as its *focal power*. Units of focal power are expressed as diopters (D) and are related to the focal length of the lens or lens surface. The *focal length* is symbolized by f or f' for primary or secondary focal length, whereas the focal power (in diopters) of the lens is symbolized by F. Because ophthalmic lenses are generally referenced by their secondary focal length and are worn in air, the relationship between focal length and focal power is expressed by the formula:

$$F = \frac{1}{f'}$$

where f' is the secondary focal length expressed in meters and 1 is the refractive index of the surrounding air. The focal length (f') must be in meters when calculating lens power.

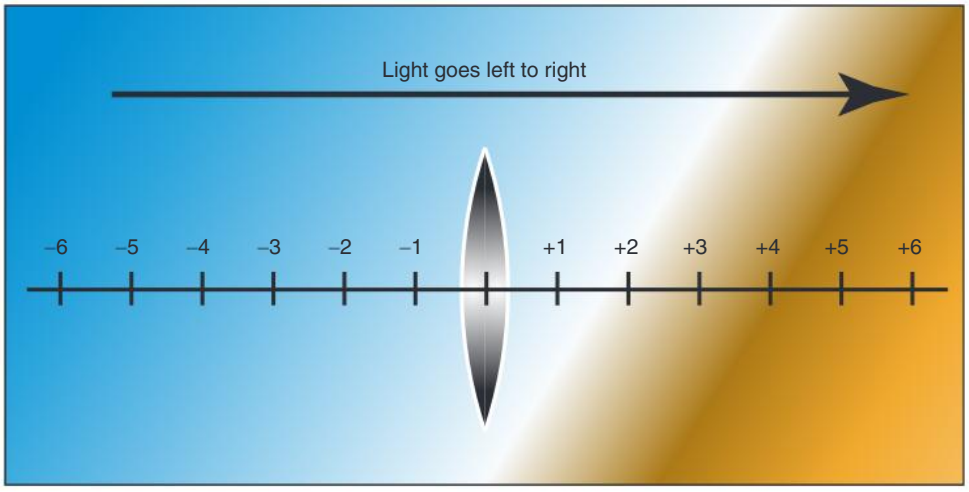


Figure 12.24 Sign convention for lens optics.

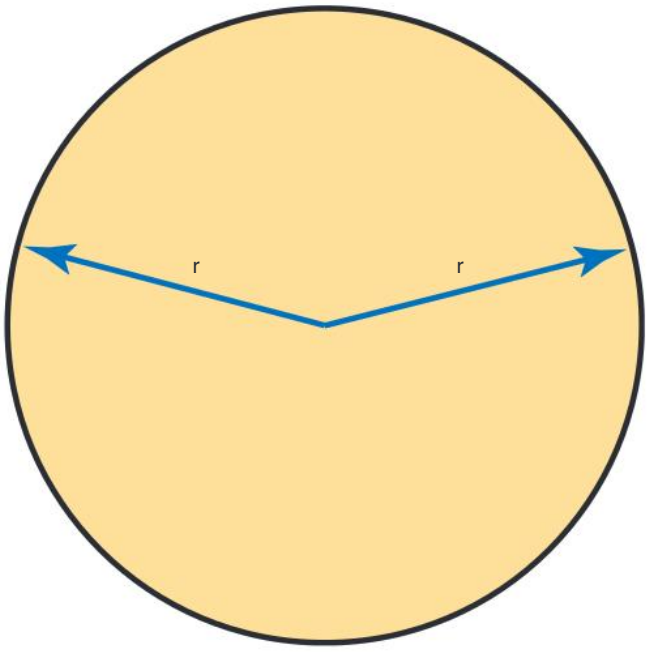


Figure 12.25 A spherically curved surface may be quantified by the radius (*r*) of curvature of that spherical surface.

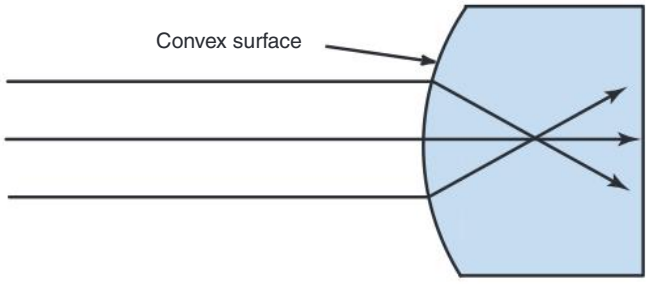


Figure 12.26 A convex surface.

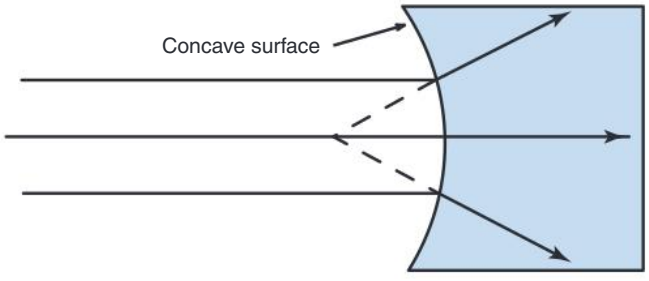


Figure 12.27 A concave surface.

Example 12.3

If a lens has a secondary focal length of +20 cm, what is the power of the lens?

Solution

Focal length first must be converted to meters:

$$+20\,\text{cm} = +0.20\,\text{m}.$$

Then lens power may be found as:

$$F = \frac{1}{f'}$$
$$= \frac{1}{+0.20}$$
$$= +5.00\,\text{D}$$

Positive Lenses and Real Images

Up to this point, the type of lens spoken of has been the type that causes parallel light rays to converge, or come together. This type of lens is referred to as a *positive,* or a *plus,* lens.

Light from an object brought to a focus by a lens will form an image of that object. In the case of converging rays, this image can be intercepted, forming an image on a screen. This type of image is known as a *real image.*

Minus Lenses and Virtual Images

According to sign convention, a lens whose focal point is to the left of the lens will have a negative, or minus, focal power. When parallel rays enter a lens that has a negative focal length (and therefore also a negative power), rays leaving the lens diverge, or spread away, from one another instead of converging toward one another.

Whereas a plus lens was described as analogous to prisms placed base to base, a minus lens can be compared with the action of two prisms placed apex to apex. The focal point of a minus lens is found by extending the diverging rays backward to a point from which they appear to originate (Figure 12.28). For a minus lens, this is the second principal focus of the lens, even though it is in front of the lens.

However, if rays of light leave the lens parallel, they must have been converging when entering the lens. The point toward which the incoming rays are converging is the first principal focus of the minus lens and is behind or to the right of the lens (Figure 12.29).

When rays diverge on leaving a lens as shown in Figure 12.28, the image of the object cannot be focused on a screen. This is because the image is formed by a backward projection of the diverging rays to their apparent point of origin. Even though they do not originate from that point, they appear as if they do. This type of image is referred to as a *virtual image.*

Example 12.4

If a lens has a secondary focal point that is 40 cm to the left of the lens (−40 cm from the lens), what focal power does the lens have?

Solution

To solve the problem, the focal length first isconverted to meters.

$$-40\,\text{cm} = -0.40\,\text{m}.$$

Next, the focal power is found by taking the reciprocal of the focal length.

$$F = \frac{1}{f'}$$
$$= \frac{1}{-0.40}$$
$$= -2.50\,\text{D}$$

The lens is found to have a power of −2.50 D.

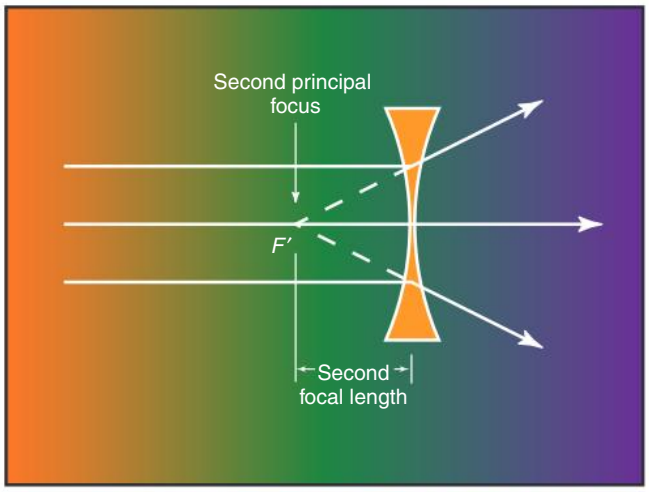


Figure 12.28 A minus lens causes parallel incoming light to diverge. The point from which light appears to diverge is the second principal focus. The image formed by the backward projection of these diverging rays is a virtual image.

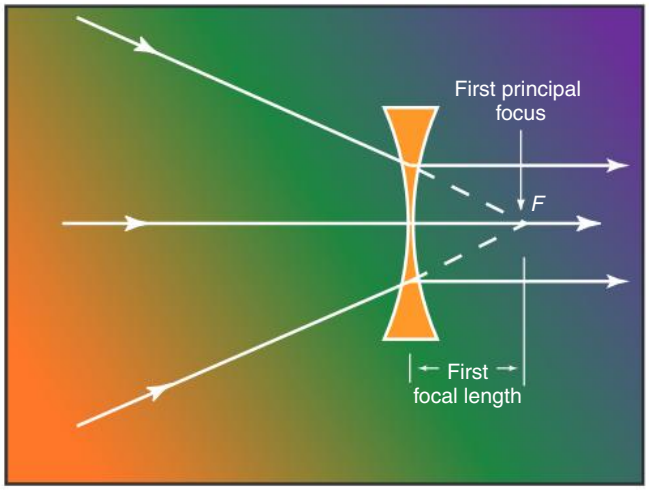


Figure 12.29 For light to leave the second surface of a lens as parallel rays, entering light rays must be converging toward the first principal focus of the lens.

Surface Power and the Lensmaker's Formula

When a lens is thin, that lens derives its total power from the combined powers of its front and back surfaces.

The amount light is bent by a lens surface depends on the radius of curvature of that surface and on the refractive index of the lens material. The formula taking these two factors into consideration when light is passing into the first surface of a lens is:

$$F_1 = \frac{n' - n}{r}$$

where F_1 = the surface power of the first surface expressed in diopters,

n' = the refractive index of the lens (i.e., the medium into which the light is entering),

n = the refractive index of air (the medium the light is leaving), and

r = the radius of curvature of this first lens surface in meters. This formula is referred to as the *Lensmaker's formula*.

It can be seen from this formula that just because two lens surfaces have the same radius of curvature, it does not necessarily mean that they will have the same ability to refract (or bend) light. The index of refraction of the material also has an effect. Therefore, two surface powers will not be the same if the index of refraction of the two materials is different. Consider, for example, a CR-39 plastic lens of index 1.498 and a higher index plastic lens of index 1.66. Assume both have a front curve with a radius of curvature of +8.66 cm. Using the Lensmaker's formula, we find the lens surface power of the CR-39 lens to be:

$$F_{1(CR-39)} = \frac{n' - n}{r} = \frac{1.498 - 1}{0.0866\ \text{m}} = +5.75\text{D}$$

However, the lens surface power of the 1.66 index plastic lens is:

$$F_{1(1.66)} = \frac{n' - n}{r} = \frac{1.66 - 1}{0.0866\ \text{m}} = +7.62\text{D}$$

It can be seen that what may appear to be a small change in refractive index can create a considerable change in surface power.

The surface power for the second surface is calculated in the same manner except that the values for n' and n are reversed. This time light is leaving the lens and reentering air. Therefore, the equation for the second, or rear, lens surface power becomes:

$$F_2 = \frac{n' - n}{r_2}$$

where n' is 1 (air) instead of the index of the lens, and n is the index of the lens instead of the index of air.

(Note: There are differences in the way that authors denote consecutive refractive indices. Instead of starting over with n and n' for the second surface, some may denote the first index of air on the left as n_1; the second index of lens material when light has entered the front surface as n_2, and the third index of air after leaving the back surface of the lens as n_3. Alternately, n_1 may be denoted simply as n; n_2 denoted as n *prime* $[n']$, and n_3 as n *double prime* $[n'']$. Any of these systems are acceptable if they are done consistently.)

One way to find the power of the lens is to add the surface powers of the front and back lens surfaces together. When lens power is found in this way, it is called the *nominal power*, or *approximate power*, of the lens. So,

$$\text{Nominal power} = F_1 + F_2$$

For low-powered thin lenses, this proves to be a fairly accurate measure of lens power. But for thick lenses, the thickness of the lens also influences lens power. Most low-powered ophthalmic lenses can be considered thin lenses. Thick lenses will be considered in Chapter 14.

THE ACTION OF A LENS ON NONPARALLEL LIGHT

The Concept of Vergence

Up to this point, only parallel light that is entering the lens from straight ahead has been considered. Such light is brought to a focus at the secondary focal point of the lens. If light entering the lens is *not* parallel, light leaving the lens will no longer come to a focus at the secondary focal point of the lens but at some other point. That point may be determined by using both:

1. A quantitative value for the vergence of light entering the lens and
2. The power of the lens.

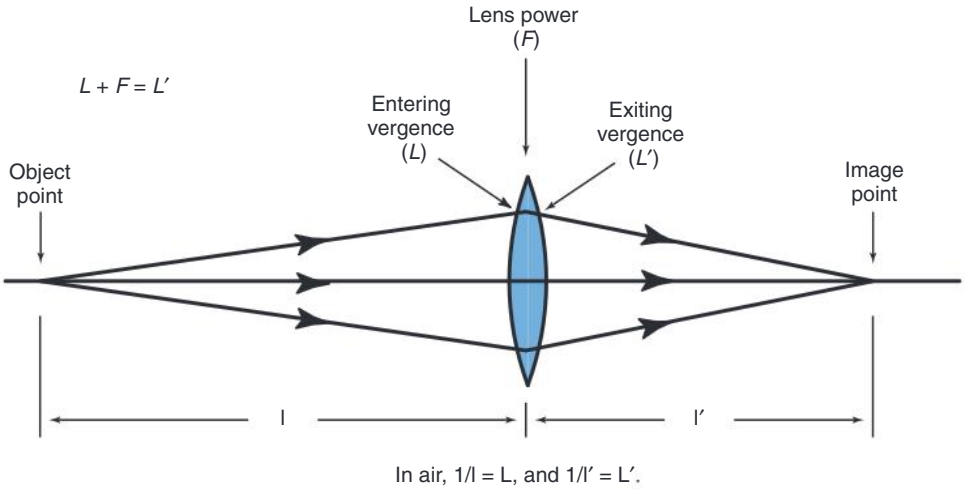


Figure 12.30 Diverging or converging light may be quantified using vergences. Object and image points of focus that correspond (as shown here) are referred to as *conjugate foci*.

Finding a Value for Converging and Diverging Light

The quantitative unit value for vergence is expressed in diopters in the same way that lens' focal powers are expressed in diopters. When light is converging, it is converging toward a certain point in space. When it is diverging, it appears to be coming from a given point in space. There are specific distances from these image or object points to the lens. These distances, or lengths, are abbreviated using the symbols l and l'. The dioptric values of the vergences are abbreviated by L and L'. The relationship between lower case l and upper case L depends upon the index of refraction and is written as:

$$\frac{n}{l} = L$$

and

$$\frac{n'}{l'} = L'$$

How do we distinguish between references to object or image points? When referring to the object, the symbols l and L are used; when referring to the image, the symbols l' and L' are used (Figure 12.30). In air, the relationship simplifies to:

$$\frac{1}{l} = L$$

and

$$\frac{1}{l'} = L'$$

There is a relationship between the entering vergence of light and the exiting vergence of light. It is as follows: The vergence of the light entering the lens (L) added to the dioptric power of the lens (F) is found to equal the vergence of the light leaving the lens (L'). This can be expressed in the form of an equation:

$$L + F = L'$$

The equation may be expressed in transposed form as $F = L' - L$. In either case, it may be referred to as the *Fundamental Paraxial Equation*. For single refractive surfaces, it is written in the more basic form:

$$F = \frac{n'}{l'} - \frac{n}{l}$$

where n' is the refractive index of the second medium into which light is entering and n is the refractive index of the first or primary medium. For thin spectacle lenses worn in air, this simplifies to:

$$F = \frac{1}{l'} - \frac{1}{l}$$

What is the situation when talking about lens surfaces only instead of whole lenses? In the instance of a single surface that separates two media, the relationship between object and image distance is determined in basically the same manner. If we substitute:

$$\frac{n' - n}{r}$$

for the surface power F, then the equation for vergence becomes:

$$\frac{n' - n}{r} = \frac{n'}{l'} - \frac{n}{l}$$

This form of the *fundamental paraxial equation* contains the term *paraxial* because the equation remains valid for those rays in the paraxial (around the axis) region of the refracting surface. Rays that strike the surface outside the central or paraxial area of the lens are called *peripheral rays* and will be affected by lens aberrations. Peripheral rays affected by lens aberrations no longer focus exactly at the focal point.

Example 12.5A

Use vergence concepts to find the convergence of light leaving a +2.50 D lens if the light entering the lens is parallel.

Solution

Since parallel light neither diverges nor converges, its vergence value is zero. Therefore, in the case of parallel light entering a +2.50 D lens, we can find the vergence of light leaving the lens as follows:

The vergence of light entering the lens is zero. Therefore,

$$L = 0.00\,\text{D}.$$

The power of the lens is +2.50 D, so

$$F = +2.50\,\text{D}.$$

If

$$L + F = L',$$

then

$$0.00\,\text{D} + 2.50\,\text{D} = L'$$

and

$$L' = +2.50\,\text{D}.$$

Therefore, the vergence of the light leaving the lens equals +2.50 D, which, as expected, corresponds to the focal power of the lens. Because the vergence of the light leaving the lens is plus in power, we know that it must be *con*verging light. By sign convention a "+" connotes a point of focus to the right of the lens.

Example 12.5B

What is the distance from the lens to the point of focus for this +2.50 D lens if the light entering the lens is parallel?

Solution

Using vergence concepts, the distance from the lens in air to the point of focus is determined by:

$$L' = \frac{1}{l'}.$$

And we know that

$$+2.50 = \frac{1}{l'},$$

which transposes to

$$l' = \frac{1}{+2.50} = +0.40\,\text{m} = +40\,\text{cm}.$$

So the point of focus is 40 cm to the right of the lens. Because the entering light was parallel, this corresponds to the secondary focal point of that lens.

Example 12.6

Light is coming from a point 40 cm in front of (to the left of) a +6.50 D lens. Assuming this to be a thin lens, use vergence concepts to determine where the image of the object is formed.

Solution

We can solve the problem with vergences using the fundamental paraxial equation

$$L + F = L'$$

We know that, in air,

$$L = \frac{1}{l}.$$

(Now as the answer progresses, follow along using Figure 12.31.)

In the example problem, the object is 40 cm in front of (to the left of) the lens. So l is −40 cm. It is negative because it is to the left of the lens, and sign convention makes it negative. It also needs to be expressed in meters for the equation to work, making l equal to −0.40 m.

$$\begin{aligned} L &= \frac{1}{l} \\ &= \frac{1}{-0.40\,\text{m}} \\ &= -2.50\,\text{D} \end{aligned}$$

Now we can use the fundamental paraxial equation to solve for the vergence of light leaving the lens.

$$\begin{aligned} L' &= L + F \\ &= -2.50 + 6.50 \\ &= +4.00\,\text{D} \end{aligned}$$

The vergence of light leaving the lens is +4.00 D. We can now find the distance from the lens to the image point. That distance is symbolized by l'. Therefore,

$$L' = \frac{1}{l'}$$

or in transposed form

$$\begin{aligned} l' &= \frac{1}{L'} \\ &= \frac{1}{+4.00} \\ &= +0.25\,\text{m} \end{aligned}$$

Converting +0.25 m into centimeters tells us that the distance of the image point from the lens is +25 cm.

Example 12.7

Light is diverging from an object 100 cm to the left of a +3.00 D lens. Use vergence concepts to determine where light will come to focus to produce an image of the object?

Solution

First, we need to find the vergence of light entering the lens. We can find that vergence because we know the light's point of origin; it is 100 cm to the left of the lens.

$$l = -100\,\text{cm} = -1.00\,\text{m}$$

The value is negative since the point of reference is to the left of the lens. As a result, light diverges from this point. Now we can find the dioptric value of that divergence.

$$L = \frac{1}{-1.00\,\text{m}} = -1.00\,\text{D}$$

So the divergence is −1.00 D. To complete the problem, we know that $F = +3.00$ D. We use the equation:

$$L + F = L'$$

and find that

$$-1.00\,\text{D} + 3.00\,\text{D} = L'$$

and

$$L' = +2.00\,\text{D}.$$

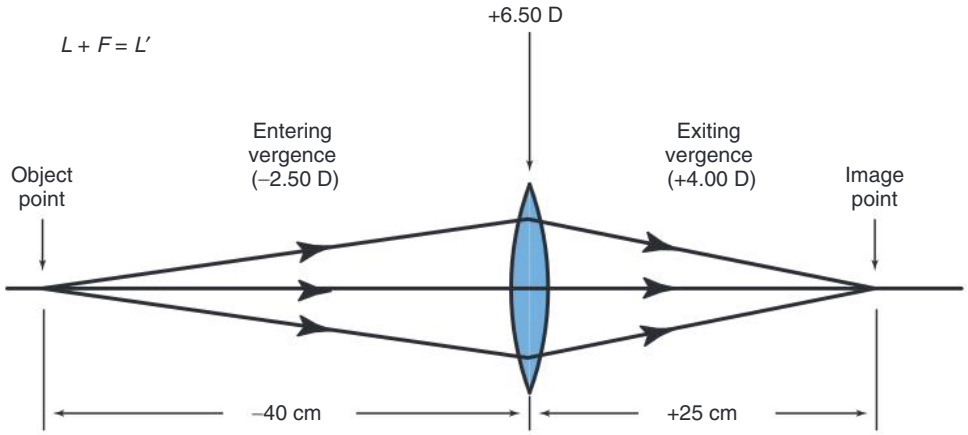


Figure 12.31 This diagram shows how vergence may be used to find the image point for an object that is at a known distance from the lens.

So the vergence leaving the lens has a value of +2.00 D.

Now we can find the distance from the lens to the focal point. This is done by taking the reciprocal value of the vergence.

$$l' = \frac{1}{+2.00\,\text{D}} = +0.50\,\text{m} = +50\,\text{cm}$$

It can be seen that if light leaves an object that is 100 cm to the left of a +3.00 D lens, it will not come to a focus at the normal secondary focal point of the lens. Instead, light coming from an object closer to the lens than infinity will focus farther to the right of the secondary focal point of the lens than it normally would for parallel incoming light.

Example 12.8

We know that a minus lens causes incoming parallel light to diverge. This places the focal point to the left of the lens, making the lens value negative and the image of the object virtual.

Now, for the problem. We have the same situation as described in the previous example; however, the +3.00 D lens is replaced with a − 3.00 D lens. Now where will the image point be for an object point 100 cm to the left of the lens?

Solution

Since the object is still 100 cm to the left, L still equals −1.00 D.

The basic equation remains:

$$L + F = L'$$

In the case of the −3.00 D lens, the appropriate substitutions are

$$-1.00\,\text{D} + (-3.00\,\text{D}) = L'$$

so,

$$L' = -4.00\,\text{D}$$

The vergence of light leaving the lens has a dioptric value of −4.00 D. Knowing this, we can find the image point.

Knowing that:

$$L' = \frac{1}{l'}$$

and substituting −4.00 D for L', we get:

$$-4.00 = \frac{1}{l'}$$

resulting in:

$$l' = -0.25\,\text{m} = -25\,\text{cm}$$

This tells us that light leaving the minus-powered lens diverges as if it were coming from a point 25 cm to the left of the lens.

SPHERES, CYLINDERS, AND SPHEROCYLINDERS

Spheres

All lenses considered thus far have a single point where light is brought to a focus. This is true even if that point must be found by extending diverging rays backward as in the case of minus lenses. When a lens has a single point focus, it is referred to as a *spherical* lens.

The surface curvature of a spherical lens duplicates the surface curvature of a sphere, or ball. A plus spherical surface can be compared with a slice off the side of a glass ball, whereas a minus spherical surface would form an exact mold for a ball of equal radius of curvature (Figure 12.32).

Spheres Correct for Nearsightedness and Farsightedness

The *sphere* is the most basic type of ophthalmic lens used and is used to correct both nearsightedness and farsightedness.

Plus spheres are used for the correction of *hyperopia,* or *farsightedness*. This occurs when light focuses behind the retina of the eye. A plus lens adds more convergence to incoming light and draws the focal point up onto the retina.

Minus spheres correct for *myopia,* or *nearsightedness*. Myopia occurs when light focuses in front of the retina. A minus lens causes the light to diverge (or converge less) before entering the eye and allows the focal point to drop back onto the retina.

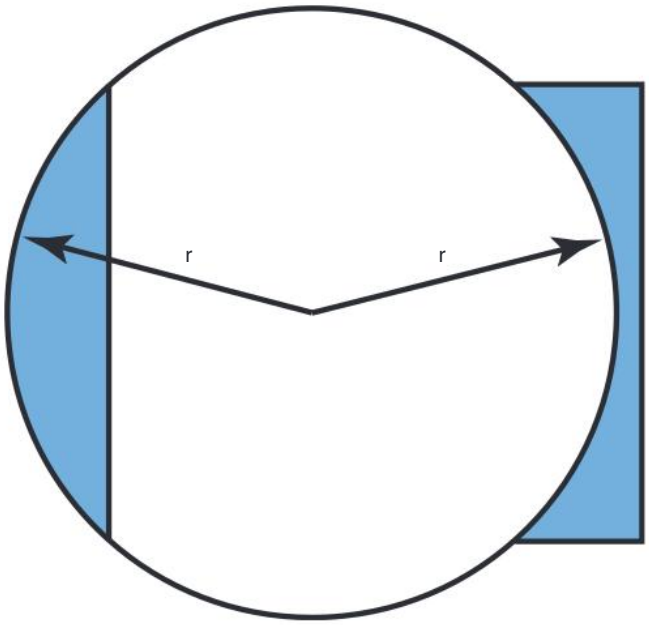


Figure 12.32 A plus spherical surface has a shape as if cut from the side of a sphere, whereas a minus spherical surface is shaped as though molded from a sphere. *r,* Radius.

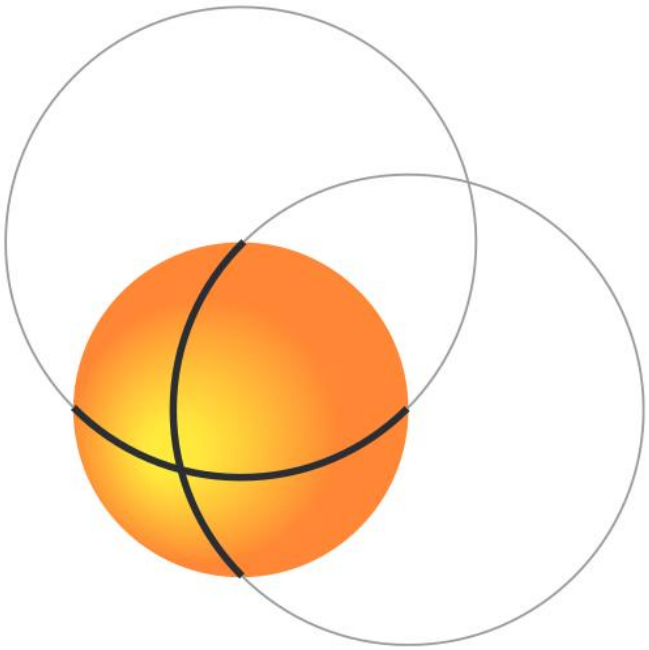


Figure 12.33 A spherical surface has the same radius of curvature in every meridian.

The Problem of Astigmatism

If a refracting surface of the eye is not spherical, the eye cannot bring light to a single point focus on the retina. For example, the front surface of the eye (the cornea) should have a front surface that is spherical, like a spherical ball such as a basketball (Figure 12.33). But instead, it may be shaped more like the surface of a football. There are now two different curves to consider: one being from tip-to-tip of the football and the other running around the central part at right angles to the first curve (Figure 12.34). Each of these two curves has its own radius of curvature.

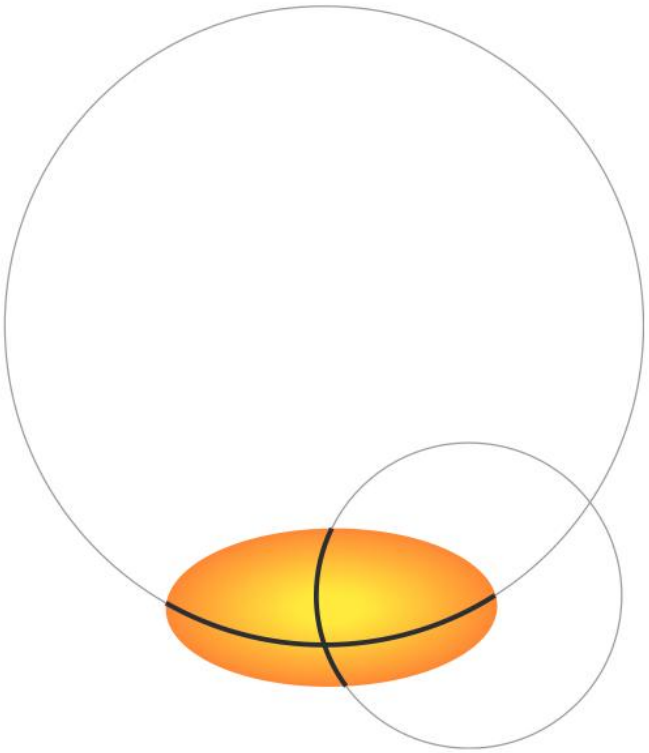


Figure 12.34 A toric surface has different radii of curvature in each of the two principal meridians.

Such a surface is called a *toric* surface. When this happens, a single point focus is no longer possible.

When an eye has two different curves on a single refracting surface, the condition is known as *astigmatism*. A situation can occur that may require a correction in only one of those two refracting meridians.

Cylinder Lenses

A lens that only has power in one meridian can be visualized as one that is cut from the side of a clear glass cylinder (Figure 12.35). A commonly occurring example of something cylindrical in shape is a pillar used to support the porch of a house. A rod is also cylindrical. The lens that optically behaves as if it were cut from the side of a glass cylinder takes on the name of the structure from which it is cut. It is, therefore, known as a *cylinder*.

Because a cylinder lens can be turned from an up-and-down to a sideways position (or to any orientation between the two), a method for specifying its exact orientation must be chosen. That method is to specify the *axis* direction. The axis of a cylinder can be thought of as being equivalent to the string threaded through the center of a cylindrical bead (Figure 12.36). As this "string" is tilted, the angle of tilt is specified by degrees. Horizontal is considered zero. The angle in degrees the "string" or cylinder axis makes with this horizontal line specifies orientation (Figure 12.37). When the cylinder axis is horizontal, instead of writing 0 degrees, it is conventional to write 180 degrees. Zero and 180 are both on the same horizontal line and, for cylinder axes, are the same. Only degrees 0 through 180 are necessary for complete specification because, as in the example shown in Figure 12.37, 210 degrees is the same as 30 degrees.

If a person is wearing a cylinder lens in a pair of glasses, the scale is always counterclockwise, or right to left, as shown in Figure 12.38. It is as if the wearer's eye was directly *behind* the scale, looking *through* it. This is true for both right and left lenses.

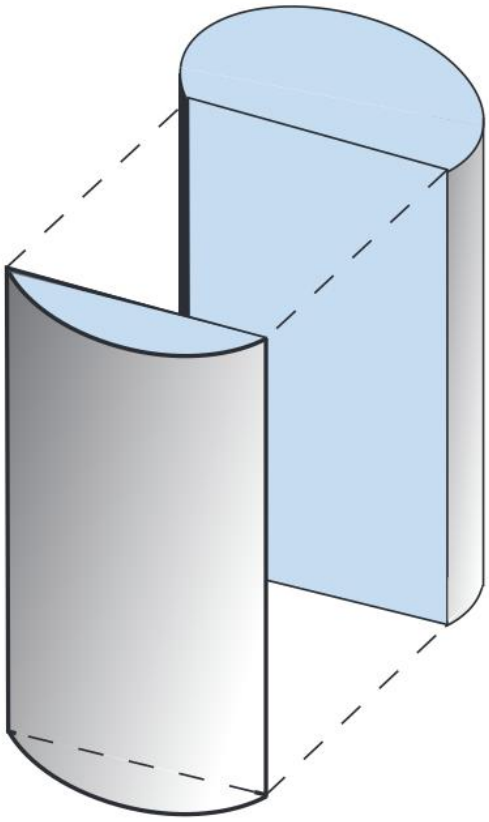


Figure 12.35 A lens shaped as though cut from the side of a clear glass cylinder is referred to as a *cylinder lens*.

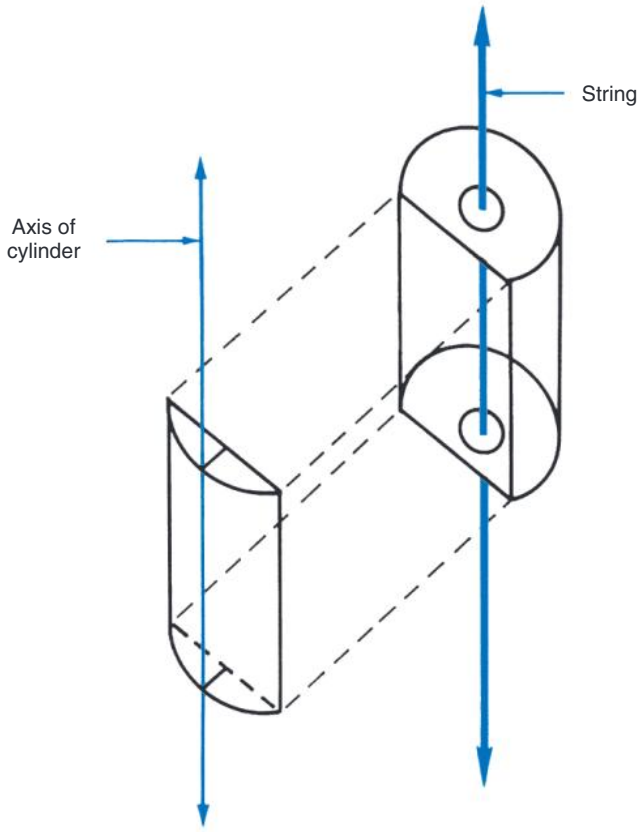


Figure 12.36 The axis of a cylinder is the reference for determining its orientation. The axis of a cylinder parallels an imaginary string running through the center of a cylindrical bead.

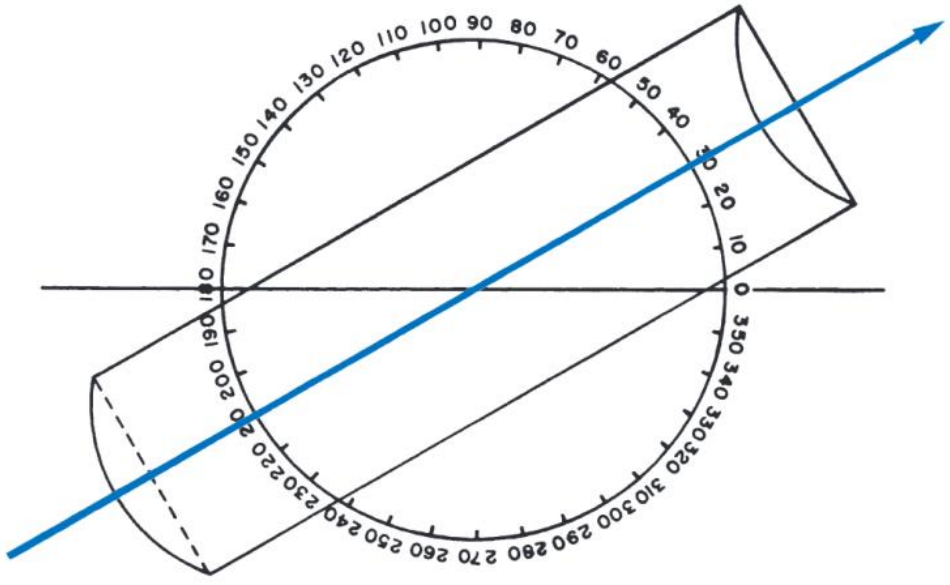


Figure 12.37 The orientation of a cylinder is specified in degrees from 0 degrees through 180 degrees. Specifying beyond 180 degrees is unnecessary because it duplicates 0 degrees through 180. (Zero degrees and 180 degrees are really the same axis. By convention 180 is used instead of 0.) In this figure, the axis of the cylinder shown is oriented at 30 degrees.

Optics of a Cylinder Lens

As previously stated, a cylinder can be used to compensate for the eye that does not bring light to a point focus. This can happen if the shape of the cornea in the 90-degree meridian is more curved than it is in the 180-degree meridian. A cylinder lens is suited for correcting this difference because light that strikes the lens along the axis of the lens will pass through that lens undeviated (Figure 12.39).

The meridian of the lens paralleling the cylinder axis is called the *axis meridian*. Along the cylinder axis, both the front and back surfaces of the cylinder are flat. So the cylinder lens has no light-refracting power along the axis of the cylinder.

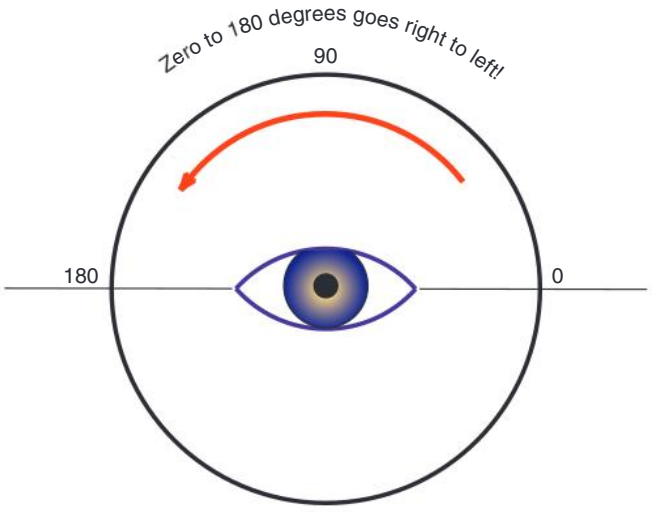


Figure 12.38 When looking at the person wearing spectacle lenses, the cylinder axis degree scale goes counterclockwise, from right to left. This is the same for both right and left eyes.

Light striking the cylinder at any other point on the lens will be bent in accordance with the power of the curved meridian of the cylinder (Figure 12.40).

The meridian of the cylinder lens at right angles to its axis has one flat surface and one curved surface. This means the lens has power in this meridian. This meridian is called the *power meridian* of the cylinder. *The axis of a cylinder is always at right angles to the power meridian of the cylinder* (Figure 12.41).

Writing Cylinder Power

As with spherical lenses, the power of a cylinder is also specified in dioptric units. Remember that the full power of the cylinder is only in the meridian opposite the axis of the cylinder. As a result, when quantifying a cylinder lens, not only must a dioptric power be specified but also the orientation of the lens axis must be specified. For instance, a cylinder may have +3.00 D of power in the horizontal meridian and zero power in the vertical meridian. The specification, therefore, would be +3.00 D cylinder power with axis at 90 degrees. This may be abbreviated +3.00 × 090, with the × being short for "axis." Because any lens with an axis orientation *must* be a cylinder, it is unnecessary to write "cylinder" or "cyl." (When a prescription is written, the cylinder axis is written as three numbers to help reduce errors through misunderstanding.)

Spherocylindrical Combinations

A cylinder lens compensates for the astigmatic eye that does not bring light to a single point focus. The proper cylinder lens will fully compensate for astigmatism. Unfortunately, much of the time astigmatism may not be the only deficiency. Once the light entering an astigmatic eye is corrected to a point focus, it may be found that the point focus is still not on the retina where it should be. The eye may still manifest myopia (nearsightedness) or hyperopia (farsightedness) and additionally need correcting with either a plus or a minus sphere lens. When this happens, it becomes necessary to use both sphere and cylinder lenses to correct the person's refractive error. When both sphere and cylinder lenses are required, the result is referred to as a *spherocylinder combination* (Figure 12.42, *A*).

In the case of a spherocylindrical combination, the effect of the two lenses together may be duplicated in the form of a single lens (see

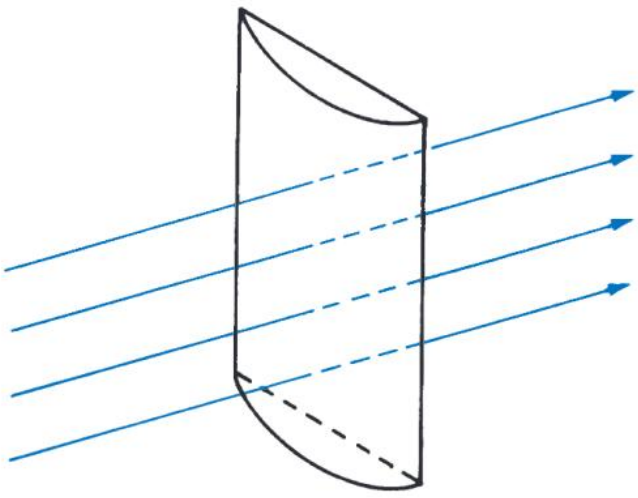


Figure 12.39 Light striking a cylinder along the cylinder axis is not bent. For a plano-cylinder, such as the one shown, both surfaces are flat along the axis.

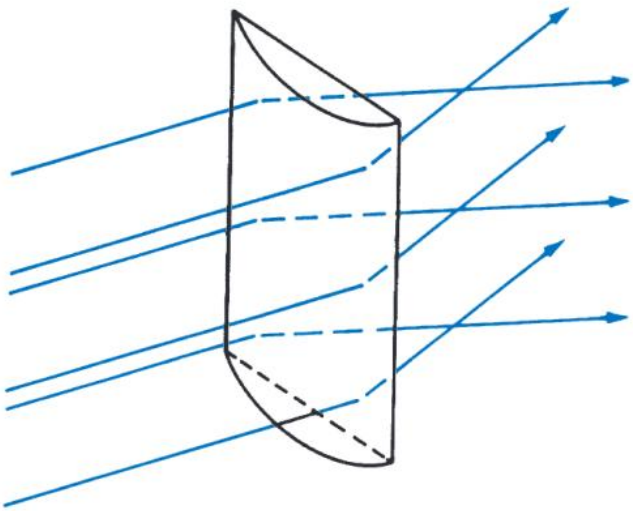


Figure 12.40 Light striking a cylinder at any other location than on the axis will be focused along a line parallel to the cylinder axis and at a constant distance from the lens.

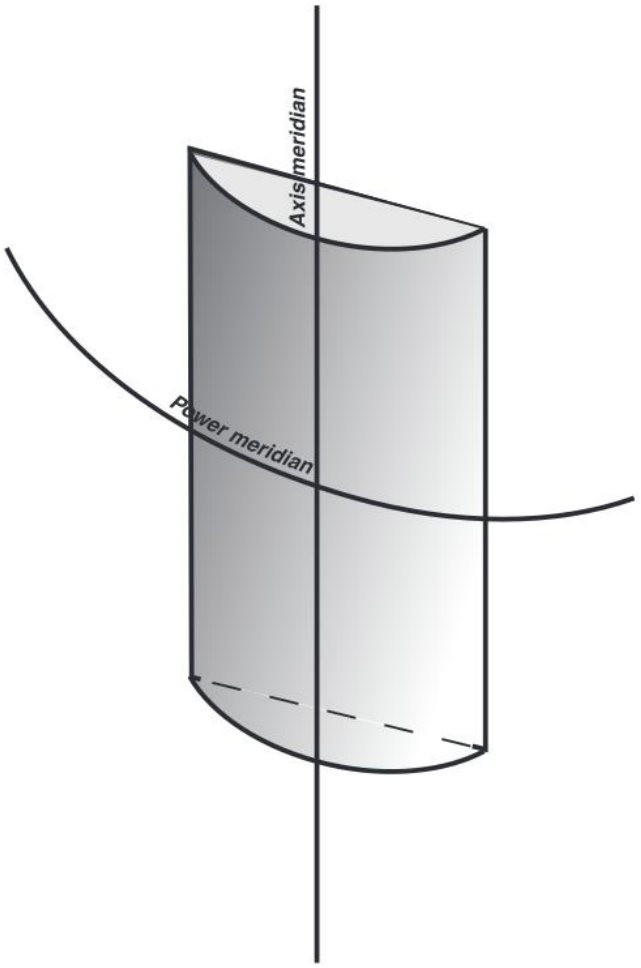


Figure 12.41 For a plano plus cylinder with a flat rear surface, imagine placing a pencil on the front surface of the lens on the cylinder axis. It rests flat on the lens. Because the back of the lens is also flat, it is easy to see that there is no power in the axis meridian. In the power meridian, however, a pencil would not sit flat on the front surface. The pencil would rock because the lens surface is curved. There is power created by the lens curve.

Figure 12.42, *B*). For example, if both the cylinder and the spherical lenses were plus, such a lens could be ground in a form as if it were cut from the side of a barrel. It can be seen from this that, as in the football example, there are two separate curves on the same lens surface.

With the addition of a sphere to the cylinder, rays traveling through the axis meridian no longer remain unbent in parallel paths as was shown in Figure 12.39 but now are caused to converge or diverge by the power of the added sphere lens (Figure 12.43, *A*). The rays striking the lens, as was shown in Figure 12.40, will be caused to focus on a line even closer to the lens than before if the added sphere is plus in power as in Figure 12.43, *B*. The combined effect is shown schematically in Figure 12.43, *C*.

Writing Spherocylinder Power

To write the power and orientation characteristics of a spherocylinder combination lens to be understandable, it becomes necessary to include sphere power, cylinder power, and cylinder axis. Such a combination is written in exactly this order: sphere, cylinder, and axis orientation in degrees.

If the sphere lens used was +5.00 D in power and the cylinder was a +3.00 D lens with the orientation of its axis at 90 degrees, the lens combination would be written as:

$$+5.00 + 3.00 \times 090.$$

This means that the prescription is the equivalent of a +5.00 D sphere lens used in combination with a +3.00 D cylinder lens with an axis of 90 degrees.

Minus Cylinder Lenses

Cylinder lenses previously described and used in examples have all been plus in power. It is also possible to have a cylinder lens that is minus in power. As with a minus sphere, a minus cylinder lens has an oppositely curved, or concave, refracting surface. The surface is such that it would cradle a cylindrical rod of equal radius (Figure 12.44). It is as if it were molded from a cylindrical rod.

As with the plus cylinder lens, the axis of a minus cylinder parallels the area of equal lens thickness. On a plus cylinder, this is along the line of maximum lens thickness; with the minus cylinder, the axis runs along the line of minimum lens thickness. To continue the analogy, a minus cylinder axis can be thought of as the imaginary string through the center of a cylindrical rod or bead against which a minus cylinder lens could rest. This meridian on the lens where the axis is found is referred to as the *axis meridian.*

There is also no power found in the axis meridian of a minus cylinder; maximum power is found 90 degrees away from it. The meridian of maximum power in a minus cylinder is still referred to as the *power meridian* (Figure 12.45).

LENS FORM

Lenses can be made in a variety of forms, with many forms possible for a lens of the same power. One lens form may be steeply curved, whereas another of identical power may appear quite flat. It is also possible to manufacture a lens of a specified power with a cylinder component on either the front or back surface.

Lens Forms a Sphere May Take

The *nominal power* of a lens is the sum of its front- and back-surface powers. When expressed as an equation, this is $F_1 + F_2 = F_{TOTAL}$. Up to this point, most lenses have been shown with one flat surface of no power and one curved surface. The curved surface makes the lens either plus or minus in power. The flat surface is referred to as *plano,* or without power.

If one surface is plano and the other an outward-curved plus surface (i.e., a *convex* surface), the lens form is referred to as *planoconvex.* If one surface is plano and the other curved inward for minus power (i.e., a *concave* surface), the lens form is *planoconcave* (Figure 12.46). If both surfaces are convex or both concave, the lens form is *biconvex* or *biconcave* (Figure 12.47). This form does not specify that both surfaces necessarily be equal in power. If this were the case, the lens form could be further classified as *equiconvex* or *equiconcave* (Figure 12.48). For example, a biconvex lens of 4.00 D of power could have surface powers, such as the following:

$$F_1 + F_2 = F_T$$
$$(+2.00\,D) + (+2.00\,D) = +4.00\,D$$
$$(+3.00\,D) + (+1.00\,D) = +4.00\,D$$
$$(+0.50\,D) + (+3.50\,D) = +4.00\,D$$

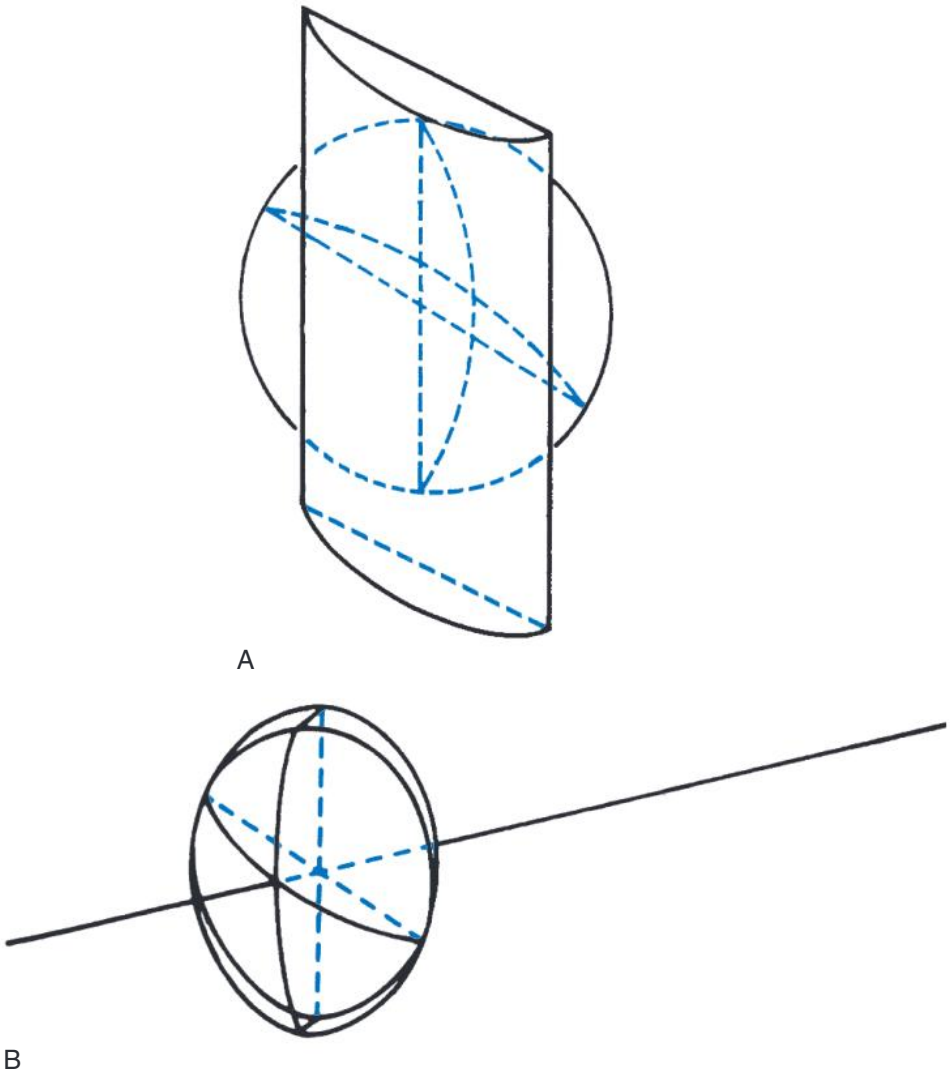


Figure 12.42 A spherocylinder combination can be thought of as just that—a sphere lens and a cylinder lens placed together **(A)**. This combined power combination may be constructed as a single lens with two curves on one surface **(B)**.

It is also possible to have a lens with one side convex (plus) and the other concave (minus). This is the most common ophthalmic lens and is referred to as a *meniscus* lens (Figure 12.49). (Note: Originally a meniscus lens was one that had a 6.00 D surface curve either on the front [+6.00 D] or on the back [−6.00 D]. Now it simply refers to a lens with a convex plus front surface and a concave minus back surface.)

The same +4.00 D lens power constructed as a meniscus lens might then have any one of the following forms, which represent only a fraction of the possibilities.

$$F_1 + F_2 = F_T$$
$$(+7.00\,\text{D}) + (-3.00\,\text{D}) = +4.00\,\text{D}$$
$$(+8.00\,\text{D}) + (-4.00\,\text{D}) = +4.00\,\text{D}$$
$$(+10.00\,\text{D}) + (-6.00\,\text{D}) = +4.00\,\text{D}$$

Lens Forms a Cylinder May Take

Even a pure cylinder may take several forms. These forms are limited only in that one meridian must have a net power of zero and the other a net power equal to the cylinder value. To keep the two meridians of a cylinder separate, it is helpful to use the concept of a power cross. A *power cross* is a schematic representation of the two principal meridians of a lens or lens surface. For a pure cylinder, these two meridians, at right angles to each other, are the axis meridian and the power meridian. A +4.00 D × 090 cylinder is schematically represented on a power cross in Figure 12.50. (Note: The terms *principal meridian* and *major meridian* are synonymous and are used interchangeably.)

In the "original," or most easily visualized form, this lens has two front curves. One is a plano surface "curve" of zero power in the 90-degree meridian and the other a +4.00 D powered curve in the 180-degree meridian. The back surface is flat, or plano, in both meridians. In this lens form, since the back surface has zero power, the front surface creates the total power of the lens.

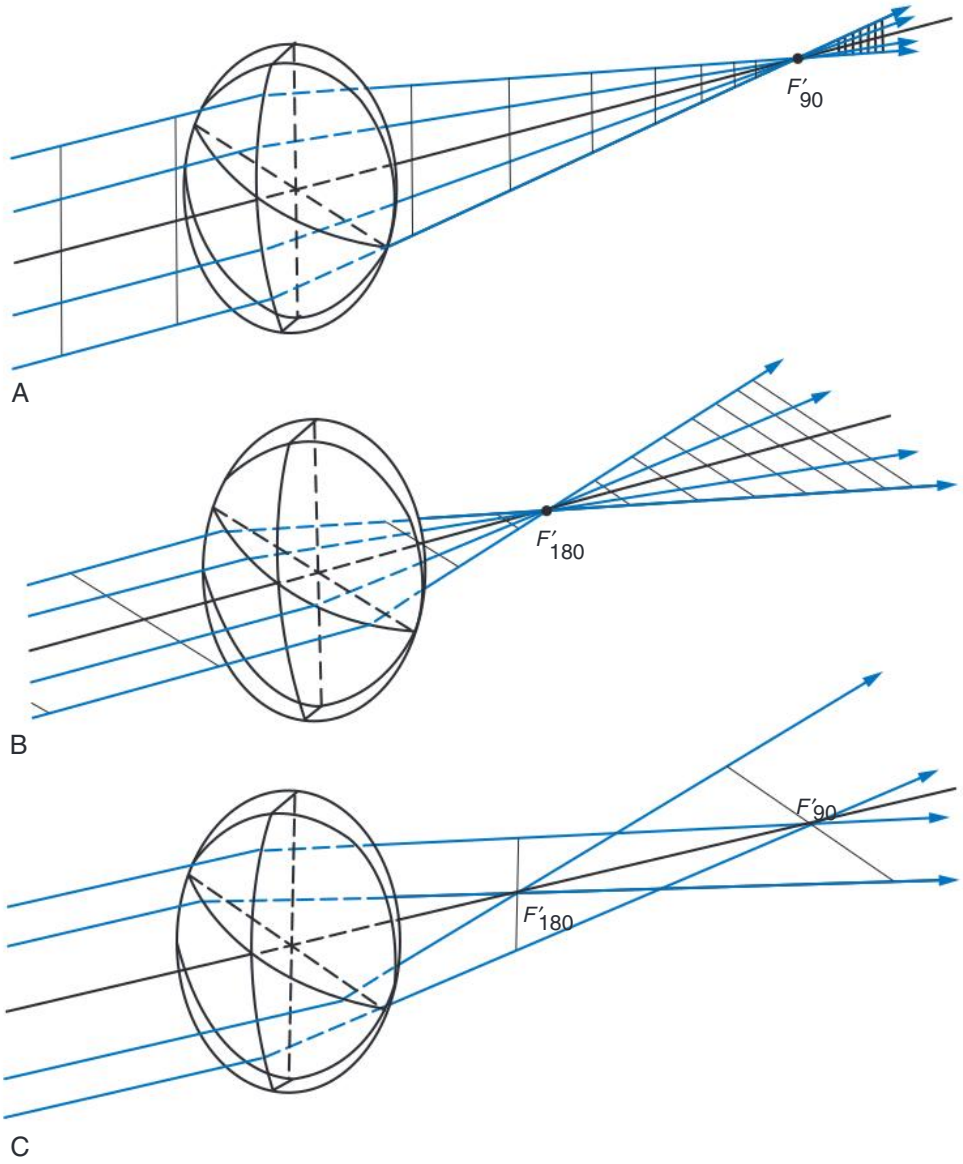


Figure 12.43 **A**, Rays previously unbent in the 90-degree cylinder axis meridian are now brought to a focus because of the addition of a plus sphere component. **B**, Rays in the 180-degree power meridian of the cylinder that were previously brought to a line focus by the cylinder are now refracted more by the additional plus sphere power. **C**, The net effect of both sphere and cylinder components results in two line foci. (It may be helpful to note that the lens shown in this figure has the same spherocylinder lens powers as was shown in Figure 12.42.)

Suppose, however, that the back surface of the lens has a power of −2.00 D in both meridians. It is still possible to construct a cylinder lens with the same total power.

For example, suppose the front-surface powers are as follows:

$$F_1 \text{ at } 090 = +2.00\,\text{D}$$
$$F_1 \text{ at } 180 = +6.00\,\text{D}$$

With the back-surface power of $F_2 = -2.00$ D, the total lens power is still +4.00 × 090. Figure 12.51 shows a series of three power crosses—one for the front surface, one for the back surface, and a third power cross for the total lens power. Both 90-degree surface meridians are added together to obtain the total lens power in the 90-degree meridian, and both 180-degree meridians are added together to obtain the total lens power in the 180-degree meridian.

When a lens has two separate curves on a surface, neither being plano but both having power, the surface is said to be *toric*.

Example 12.9

Suppose a lens has a toric front surface. F_1 in the 90-degree meridian is +4.00 D, and F_1 in the 180-degree meridian +6.00 D. If the back surface has a surface power of −4.00 D, what is the total power of the lens?

Solution

The simplest method of solving the problem is to first draw three empty power crosses representing F_1, F_2, and F_T (Figure 12.52, *A*). Next, the known component may be written in at the proper meridians for F_1 and F_2 (see Figure 12.52, *B*). Surface powers are then added together to obtain the total power of the lens (see Figure 12.52, *C*). Last, these powers are taken off the power cross and written in abbreviated form. In this case, a +2.00 × 090 cylinder is obtained.

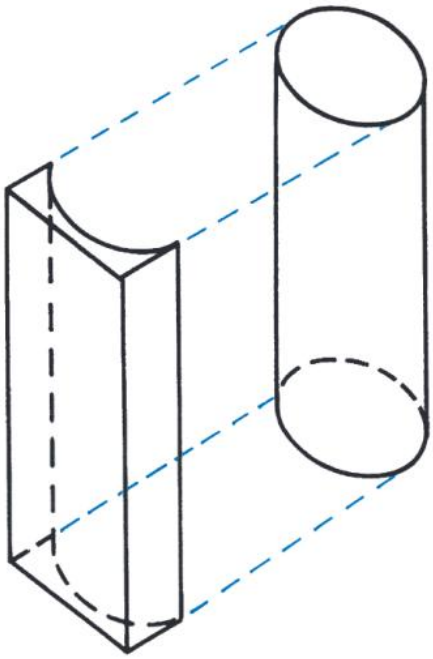


Figure 12.44 A minus cylinder lens can be thought of as if molded from a cylindrical rod.

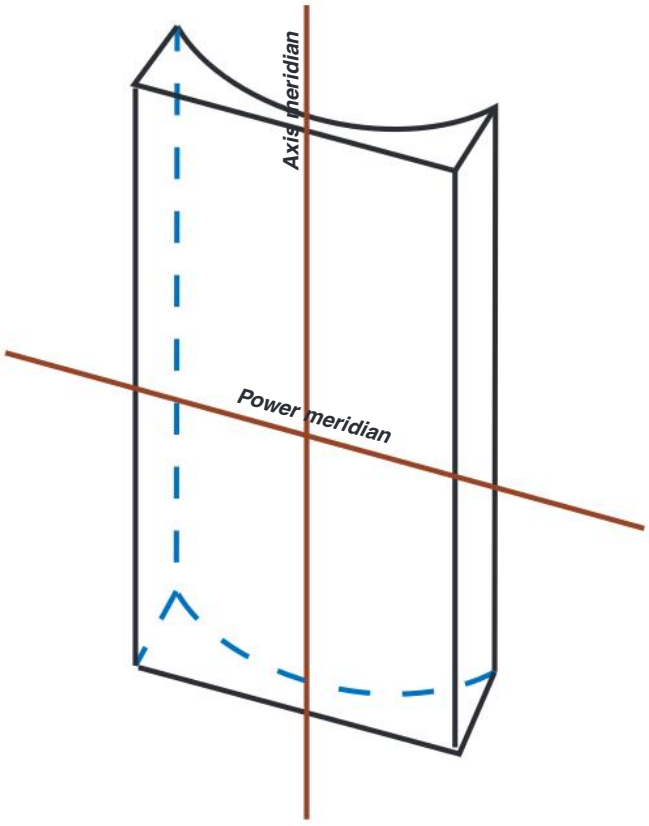


Figure 12.45 Power and axis meridians shown for a minus cylinder.

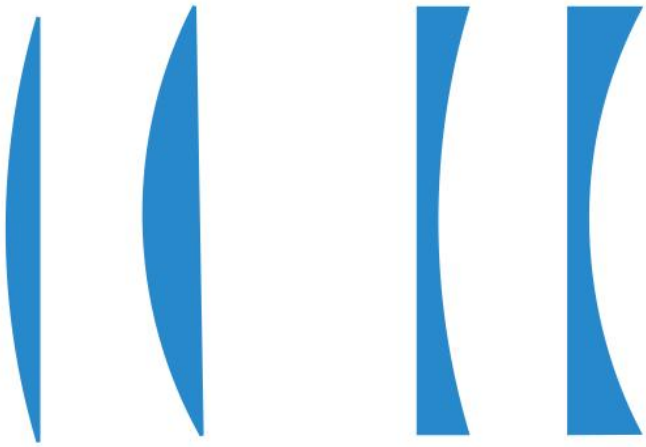


Figure 12.46 Two planoconvex lenses are shown on the left, and two planoconcave lenses are shown on the right.

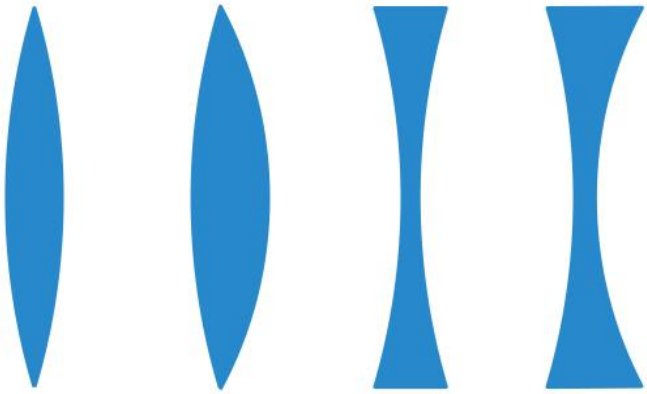


Figure 12.47 Two biconvex lenses are shown on the left, and two biconcave lenses are shown on the right.

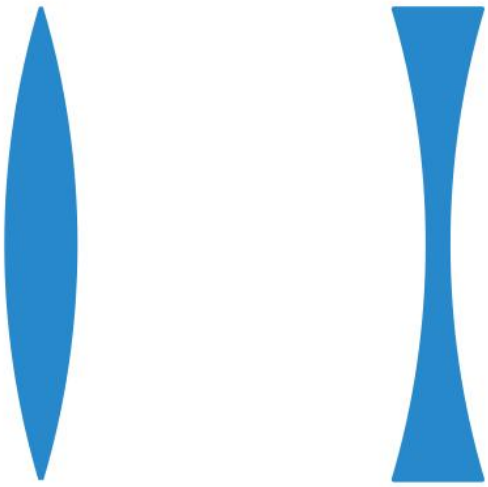


Figure 12.48 Equiconvex and equiconcave lenses must have the same curvature on both front and back surfaces.

Figure 12.49 A meniscus lens has a plus (convex) surface on one side of the lens and a concave (minus) surface on the other.

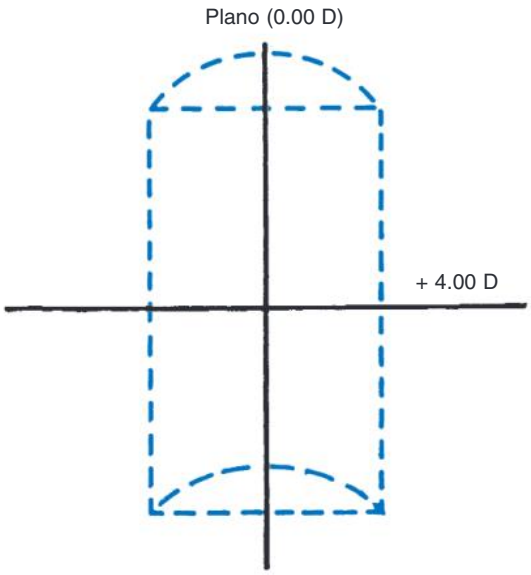


Figure 12.50 This is a power cross for a +4.00 × 090 cylinder lens. The outlined cylinder is for reference only, never appearing on an actual power cross.

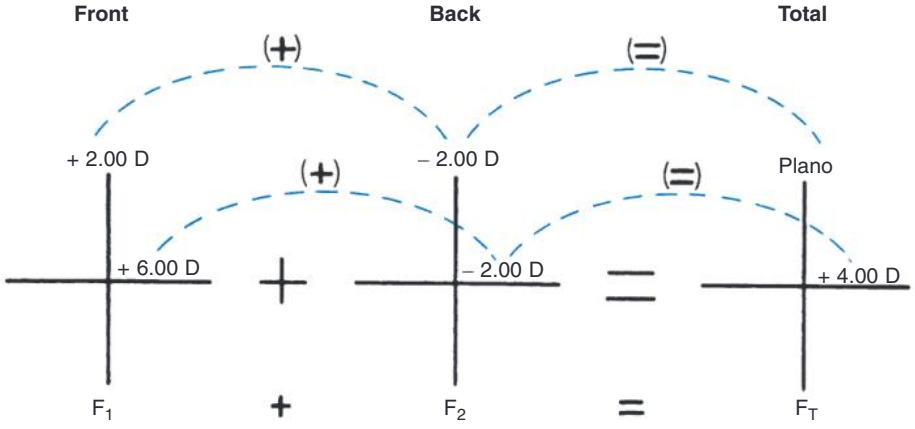


Figure 12.51 For this lens, the front surface is the toric surface with two different lens powers. The back surface is spherical, so both 90-degree and 180-degree back-surface meridians have the same power. The total power of the lens can be found by adding corresponding surface meridians together—90 with 90 and 180 with 180.

Plus and Minus Cylinder Form Lenses

When the lens obtains its cylinder power from a difference in power between two *front*-surface meridians (i.e., a toric front-surface lens), the lens is said to be ground in *plus cylinder form*. If, on the other hand, a lens has a cylinder component, but the cylinder power is a result of a difference in power between two *back*-surface meridians (i.e., a toric rear surface lens), it is a *minus cylinder form lens*. In other words, the plus cylinder form lens has two different power curves on the front and one spherical curve on the back, whereas a minus cylinder form lens has one spherical curve on the front and two different power curves, making up the cylinder component, on the back.

Example 12.10

If a lens has dimensions of $F_1 = +6.00$ D, F_2 in meridian $090 = -8.00$ D, and F_2 in meridian $180 = -6.00$ D, what form does the lens have, and what is its total power?

Solution

Because the cylinder component is on F_2, the back surface, the lens is minus cylinder in form. To find the total lens power, the front- and back-surface power crosses are mapped out and added together (Figure 12.53).

F_1 in meridian $90 = +6.00$ D F_1 in meridian $180 = +6.00$ D
F_2 in meridian $90 = -8.00$ D F_2 in meridian $180 = -6.00$ D

F_T in meridian $90 = -2.00$ D F_T in meridian $180 = 0.00$ D (plano)

The power of this cylinder is in meridian 090 which means that the axis is meridian 180. In abbreviated form, the lens may be written as -2.00×180.

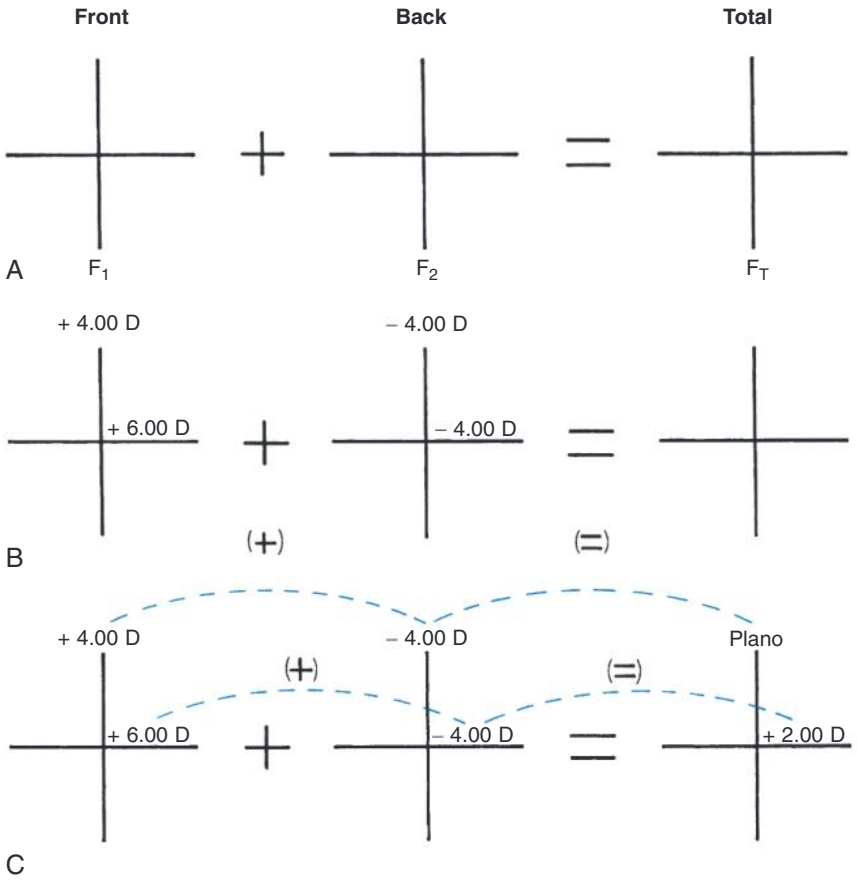


Figure 12.52 Steps in solving lens form power problems consist of drawing the appropriate series of crosses **(A)**; writing all known lens powers on the crosses **(B)**; and solving for the remaining unknown factors **(C)**.

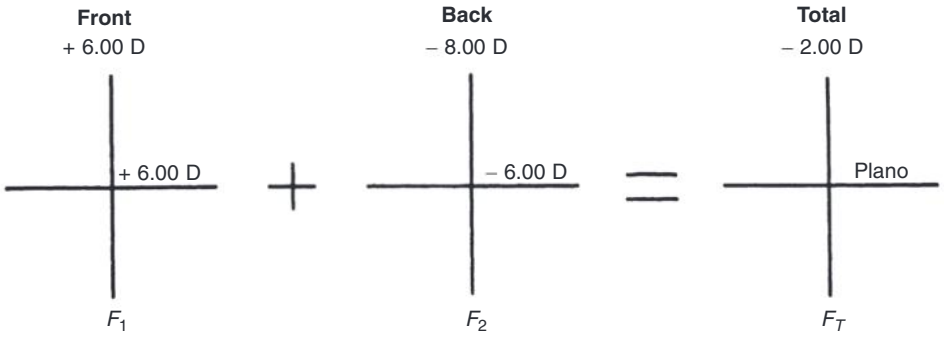


Figure 12.53 The lens represented on this power cross series is minus cylinder in form since the toric surface is on the back of the lens.

Lens Forms a Spherocylinder May Take

Minus Cylinder Form

As seen earlier, either a sphere or a cylinder lens may be constructed in several different forms, all having the same total power (F_T). In the same way it is also possible to construct a spherocylinder lens in several different forms, all having the same total spherocylinder power.

Example 12.11

A lens has the following form:

A spherical front-surface power (F_1) of +3.00 D.
A cylindrical back surface where
F_2 in meridian 090 equals 0 and
F_2 in meridian 180 equals −2.00 D.

Is the lens constructed in plus or minus cylinder form? What is the power of the lens?

Solution

To tell if the lens is constructed in plus or minus cylinder form, we need only look to see which surface has two powers. If the cylinder power comes from the front surface, the lens is plus cylinder in form. If the cylinder power is on the back of the lens, the lens is minus cylinder in form. This lens has the cylinder on the back, and thus is a minus cylinder form lens.

To find the power of the lens, draw three sets of power crosses—one for the front surface, one for the back surface, and one for the total power of the lens. Enter the front- and back-surface powers on the front- and back-surface power crosses as shown in Figure 12.54.

Once front- and back-surface powers are entered on the power crosses, add the front- and back- surface 90-degree meridians together.

$$(+3.00) + (0.00) = +3.00$$

The +3.00 D power is entered on the 90-degree meridian of the last power cross.

The same is done for the 180-degree meridian.

$$(+3.00) + (-2.00) = +1.00$$

The +1.00 D power is entered on the 180-degree meridian of the last power cross. The last power cross shows the total lens power.

In a pure cylinder lens having no spherical component, since one meridian is zero, the other meridian shows the exact cylinder power. As expected, the cylinder power is the difference between the two meridians.

In the case of a spherocylinder lens in which *both* meridians have power, the cylinder power is still the numerical difference between the two meridians. In the example, the difference between +1.00 and +3.00 is 2.00. This means that the cylinder power is 2.00 D. It may be either a +2.00 D or a −2.00 D cylinder, depending on how the prescription is to be written.

Power can be interpreted from information given on a power cross as follows: If the prescription is to be written with the cylinder as a minus cylinder (in minus cylinder form), the most plus (or least minus) value is the sphere power. In this case, the +3.00 is the sphere power because it is the most plus.

Since the cylinder value is 2.00 D *less* than the +3.00 D sphere, the *difference* is the power of the cylinder (−2.00). The abbreviated minus cylinder form for this lens combination then becomes +3.00 − 2.00 × 090. It is helpful to remember that *the cylinder axis always falls in the meridian that represents the spherical power of the lens.*

Example 12.12

Suppose a lens has a front-surface power of +8.00 D. The back-surface power is −7.00 D in the 90-degree meridian and −6.00 D in the 180-degree meridian. What is the total power of the lens when written in minus cylinder form?

Solution

Again, draw three power crosses for front-surface, back-surface, and total lens power. Enter the +8.00 D on both meridians of the front-surface power cross. A spherical surface always has the same power in every meridian.

Enter the back-surface values on the second surface power cross as shown in Figure 12.55.

Now add the 90-degree powers together and the 180-degree powers together to get the total as shown in Figure 12.55.

To write the resultant lens formula in minus cylinder form, the most plus meridian becomes the sphere component (+2.00). The difference between the two meridians is 1.00. The prescription, written in minus cylinder form, becomes +2.00 − 1.00 × 180.

Plus Cylinder Form

A minus cylinder form lens gets the cylinder power from the back surface of the lens. A plus cylinder form lens has the cylinder power difference on the front surface. So a plus cylinder form lens may be constructed such that the front surface is toric and the back surface spherical. A lens with the same power may be constructed in plus cylinder form or minus cylinder form.

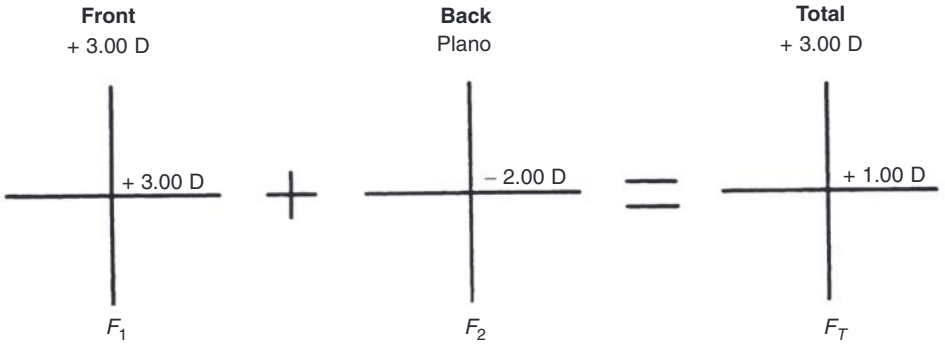


Figure 12.54 Front and back curves and total lens power for a spherocylinder lens.

Example 12.13

Find the power of a lens having a toric front surface of F_1 in meridian 90 equal to +7.00 D and F_1 in meridian 180 equal to +8.00 D. The power of the back surface is −6.00 D. Write the results in plus cylinder form.

Solution

The data are entered on a set of power crosses shown in Figure 12.56, and total power (F_T) is calculated. Notice that the power cross reflects the same results as were found for the minus cylinder lens of Figure 12.55, even though the lens has a different form.

The difference between the two power meridians for the total lens power is 1.00 D. However, if we are to write this lens as a plus cylinder lens, we need to write the cylinder power as +1.00 instead of −1.00. So which power on the power cross is the sphere power? Is it the +1.00 D power or the +2.00 D power?

Expressing the written lens power in plus cylinder form means that the cylinder value is "in addition to" the value of the sphere. The value of the sphere is, therefore, the *least plus* (or most minus) of the two values. In Figure 12.56 this is the +1.00 D meridian. The second meridian is 1.00 D greater than the sphere value, so the cylinder is +1.00 D.

By definition, the axis of a cylinder is 90 degrees away from the cylinder power meridian (i.e., the axis meridian in the sphere power meridian). In our example, the plus cylinder axis is at 090 degrees. The lens prescription written in plus cylinder form will therefore be:

+1.00 D sphere in combination with + 1.00 cyl × 090

or

+1.00 + 1.00 × 090.

Toric Transposition

It has been shown that it is possible to have a spherocylindrical lens of the same power expressed in at least two different lens forms and written in two different ways. These are either the plus or the minus cylinder form of prescription writing. Most logically, one would assume that the plus cylinder form of prescription writing would be used exclusively for lenses with a toric front surface and the minus cylinder form of prescription writing for lenses with the toric surface on the back. *This, however, is not the case!* Instead of indicating the location of the toric surface for the prescribed lens, the written form usually only indicates the type of lenses used during the examination process. In the past, optometrists wrote prescriptions in minus cylinder form, and ophthalmologists traditionally wrote prescriptions in plus cylinder form. This is no longer universally true. However, prescriptions of both forms are commonly seen.

Even though prescriptions are still commonly written in both plus and minus cylinder forms, there is now a high consistency in how spectacle lenses are made. Almost every lens used for prescription eyewear now has the toric surface on the back, making it a minus cylinder form lens. If a prescription written as a plus cylinder is sent to the lab, the order will be fulfilled with a toric back surface. In other words, the cylinder power will be on the back surface.

Because lens prescriptions may be written in either plus or minus cylinder form, it is necessary to be able to convert or *transpose* from one form of prescription writing to the other. This process is known as *toric transposition.*

Steps for transposing from one form of prescription writing to the other are as follows:

1. Add the sphere and cylinder values to obtain the new sphere value, being certain to include the signs in your calculation.
2. Change the sign of the cylinder (plus to minus or minus to plus).
3. Change the axis by 90 degrees. (This can be done by addition *or* subtraction since the result is the same. The answer for the axis, however, must be from 1 to 180 degrees. An answer of 190 degrees, for example, is not acceptable.)

Example 12.14

Transpose the written minus cylinder lens prescription of +2.00 − 1.00 × 180 into plus cylinder form.

Solution

1. For the first step add the sphere and cylinder powers together. This will be (+2.00) + (−1.00) = +1.00. Therefore, the new sphere value is +1.00 D.
2. Change the sign of the cylinder. The new cylinder power becomes +1.00 D.
3. Change the axis by 90 degrees. If 90 degrees is added to 180 degrees, a value of 270 degrees is obtained. If 90 degrees is subtracted from 180 degrees a value of 90 degrees is obtained. A cylinder axis runs through *both* 90 and 270 degrees. By convention, only values between 0 and 180 are used, making 90 the appropriate value. The new cyl axis is 090.
4. The new written lens form is +1.00 + 1.00 × 090.

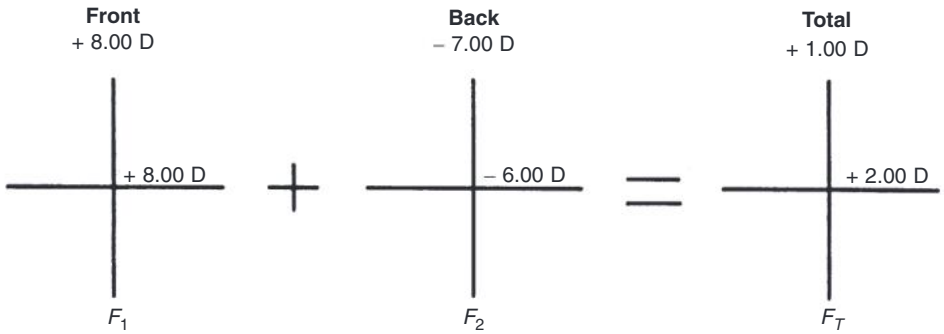


Figure 12.55 This spherocylinder lens is a minus cylinder form lens.

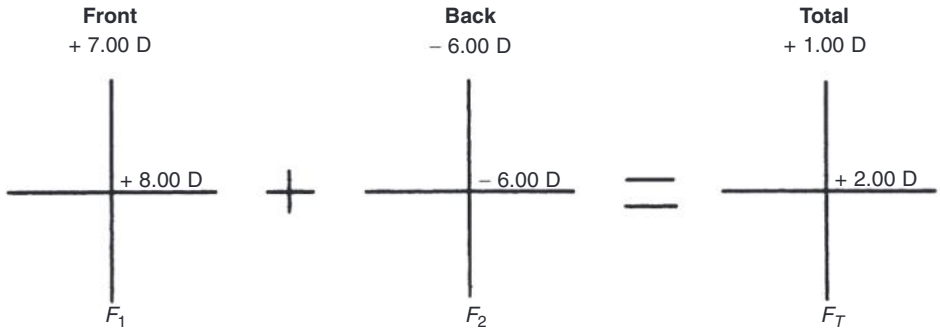


Figure 12.56 The spherocylinder lens shown here is in plus cylinder form. Notice that this figure and Figure 12.55 have the same F_T values despite differences in cylinder form.

Crossed-Cylinder Form

Another possible abbreviated form of prescription writing is the *crossed-cylinder form*. This form is never used to write a prescription for spectacle lenses. However, an understanding of this form of prescription writing aids in a more complete understanding of lenses. The crossed-cylinder form of prescription writing is also the way that keratometer readings are written when measuring the front-surface power of the cornea for contact lens purposes.

To understand the crossed-cylinder form of prescription writing, think through the following:

- If two spherical lenses are placed together, a new sphere power results from the sum of the two.
- If a sphere and a cylinder are placed together, a spherocylinder results.
- If two cylinders are placed together with axes 90 degrees apart from one another, a sphere, a cylinder, or a spherocylinder may result.

Suppose, for example, +1.00 × 180 and +2.00 × 090 lenses are placed together. These are both cylinders, and their axes are "crossed" in relationship to one another. In abbreviated crossed-cylinder form, this reads as:

$$+1.00 \times 180 / +2.00 \times 090$$

This would be spoken as "plus one, axis one-eighty, in combination with plus two, axis ninety." On a power cross, this would appear as shown in Figure 12.57. Note that the combination of these two crossed cylinders results in the same total power as shown in Figures 12.55 and 12.56. Because all three of these lenses have the same total power, these two crossed cylinders could be written in crossed-cylinder form, plus cylinder form, or minus cylinder form.

The simplest and most direct method of transposing from plus or minus cylinder form into crossed-cylinder form is to first place the powers on a power cross. In that form, the power observed for each principal meridian is the power of one of the two "crossed cylinders." The location of the axis for each of these two cylinders is 90 degrees away from its meridian of power.

An Alternate Crossed-Cylinder Form

The normal way of writing a lens prescription in crossed-cylinder form is done just like writing a plano- cylinder. When the +1.00 × 180 and +2.00 × 090 lenses were placed together in the example just given, the crossed-cylinder combination was written as:

$$+1.00 \times 180 / +2.00 \times 090$$

The powers were referenced to the axis meridians because the lens was considered as if it was two plus cylinders combined, as was shown in Figure 12.57. Sometimes the powers are referenced to their power meridian instead of their axis meridian. The +1.00 cylinder has power "at" (in) the 90-degree meridian. The +2.00 cylinder has power "at" (in) the 180-degree meridian. So the power could be written as:

$$+1.00 \text{ @ } 090 / +2.00 \text{ @ } 180$$

This is spoken as "plus one at ninety in combination with plus two at one-eighty." This form is seen in contact lens practice when reading or writing the keratometer reading of the front surface of the cornea. Of course, the powers are considerably higher and might look something like this:

$$+42.50 \text{ @ } 180 / +43.75 \text{ @ } 090$$

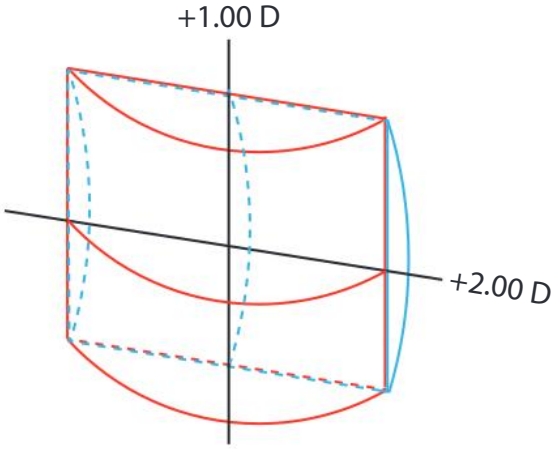


Figure 12.57 Writing lens power in crossed-cylinder form is easier when the cylinder components are visualized on a power cross. In crossed-cylinder form, the total prescription shown on the black power cross can be represented by the combination of two plano-cylinders. One is a pl +2.00 × 090 cylinder shown in red. The other is a pl +1.00 × 180 cylinder shown in blue. When combined together, this would be written in crossed-cylinder form as +2.00 × 090/+1.00 × 180.

The Spherical Equivalent

A spherocylinder lens will correct for astigmatism and myopia or hyperopia. If it were necessary to correct a nearsighted or farsighted person who also has astigmatism but there were no cylinder lenses available, what would be the best correction using only a sphere lens?

Looking back to Figure 12.43, *C*, we see how a spherocylinder lens has two focal lines. If only a sphere lens is to be used, the best sphere lens will be one that has its focal point corresponding to a dioptric value halfway between the dioptric values of the two focal lines formed by the spherocylinder lens. The location halfway between the two dioptric values of the spherocylinder lens is called the *circle of least confusion* because the rays of light do not come to a point focus at this location but, instead, form a circle. This spherically powered replacement for the spherocylinder lens is called the *spherical equivalent.*

How to Find the Spherical Equivalent

To find the spherical equivalent of a spherocylinder lens:

1. Take half the value of the cylinder and
2. Add it to the sphere power.

In other words, as a formula the spherical equivalent is:

$$\text{Sphere} + \frac{\text{Cylinder}}{2} = \text{Spherical equivalent}$$

Note that the halfway location of the circle of least confusion is not at the physical or linear halfway point between the two focal lines. Instead, it will be at a point that is based on the dioptric value halfway in between the two powers. For example, a lens with a power of +1.00 +2.00 × 180 has two focal lines—one for the +1.00 D power meridian, the other for the +3.00 D power meridian. These lines are at distances of +100 cm and +33.3 cm from the lens. The physical halfway point would be +66.7 cm from the lens. However, the location of the circle of least confusion is determined by the spherical equivalent of the lens. The spherical equivalent is +2.00 D. The focal point of +2.00 is at +50 cm, not +66.7 cm. Therefore, the circle of least confusion is located at a distance of +50 cm from the lens.

Example 12.15

What is the spherical equivalent for this lens?

$$+3.00 - 1.00 \times 180$$

Solution

Using the formula for the spherical equivalent, we have:

$$\begin{aligned}\text{Spherical equivalent} &= +3.00 + \frac{-1.00}{2} \\ &= +3.00 + (-0.50) \\ &= +2.50\,\text{D}\end{aligned}$$

Example 12.16

What is the spherical equivalent for a lens having a power of −4.25 − 1.25 × 135?

Solution

Again, using the formula, we find the spherical equivalent as:

$$\begin{aligned}\text{Spherical equivalent} &= (-4.25) + \frac{-1.25}{2} \\ &= (-4.25) + (-0.625) \\ &= -4.875\,\text{D}\end{aligned}$$

REFERENCE

1. Torgersen DT. Reference Wavelength and Lens Power, OLA News. CLEARVisions; 2020. Jan/Feb.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. A laser pointer is pointed at the surface of a pond at an angle. The angle of incidence of the beam is 40 degrees. Some of the light is reflected by the surface, and some is refracted. To the nearest degree, what are the angles of reflection and refraction? (Water has a refractive index of 4/3, or 1.33.)
   - **a.** Angle of reflection = 59 degrees; angle of refraction = 40 degrees
   - **b.** Angle of reflection = 50 degrees; angle of refraction = 29 degrees
   - **c.** Angle of reflection = 40 degrees; angle of refraction = 59 degrees
   - **d.** Angle of reflection = 40 degrees; angle of refraction = 29 degrees
2. Suppose a scuba diver swimming underwater was able to shine a laser pointer upward and the beam of light strikes the surface at an angle of incidence of 37 degrees. As the beam leaves the water and goes into the air, is the refracted beam bent toward or away from the normal (perpendicular) to the surface? Just what is the angle of refraction (to the nearest degree)? (The refractive index of water is 4/3, or 1.33.)
   - **a.** Away, 27 degrees
   - **b.** Toward, 53 degrees
   - **c.** Toward, 27 degrees
   - **d.** Away, 53 degrees
3. A ray of light strikes a slab of clear plastic at an angle of incidence of 8 degrees. The plastic has an index of refraction of 1.5. If the plastic slab is 5 cm thick with parallel sides, assuming the surrounding medium is air, with what angle does the light leave the plastic after passing through it?
   - **a.** 5.0 degrees
   - **b.** 5.3 degrees
   - **c.** 8.0 degrees
   - **d.** 12.0 degrees
4. A lens has a focal length of +66.67 cm. What is its power?
   - **a.** +1.50 D
   - **b.** +3.00 D
   - **c.** +6.67 D
   - **d.** +0.02 D
5. If a lens has a power −7.12 D, what is its focal length?
   - **a.** +13 cm
   - **b.** −0.1404 m
   - **c.** +14.04 cm
   - **d.** 5 in
6. A + 2.50 D lens has a focal length of +40 cm. If the power of this lens is doubled, the focal length:
   - **a.** is doubled.
   - **b.** is halved.
   - **c.** is quartered.
   - **d.** remains the same.

7. Light that enters a lens in parallel rays produces a virtual image 0.50 m in front of the lens. What is the power of the lens?
   a. +0.50 D
   b. −0.50 D
   c. −2.00 D
   d. +2.00 D
   e. +5.00 D
8. A curved refracting surface is made from material of refractive index 1.50. It has a radius of curvature of +8.00 cm. To the nearest 0.125 D, what power does the lens surface have in air?
   a. +0.50 D
   b. +6.25 D
   c. −0.62 D
   d. −3.25 D
9. An object is located −15 cm from a −15.00 D lens. How far from the lens is the image point located?
   a. −6.67 cm
   b. −1.2 cm
   c. −12 cm
   d. +0.046 m
   e. −4.6 cm
10. A lens has a front-surface power in air of +3.50 D. If the radius of curvature of the front surface is +20 cm, what index of refraction does the lens have?
    a. 1.33
    b. 1.50
    c. 1.60
    d. 1.70
    e. 1.80
11. An object is positioned 50 cm in front of a −4.00 D lens. How far from the lens will the image of this object be?
    a. +50 cm
    b. −50 cm
    c. −16.67 cm
    d. −19.33 cm
12. A lens has +2.50 D of power and causes an image to form at +33.33 cm. Where is the object point located?
    a. +2.00 m
    b. −50 cm
    c. −18 cm
    d. +18 cm
13. A cylinder lens has a power of +2.00 D and an axis orientation of 25 degrees. Where is the meridian of minimum power?
    a. 25 degrees
    b. 115 degrees
    c. 70 degrees
    d. 160 degrees
14. For a plano-cylinder, light passes through the _____ meridian undeviated.
    a. power
    b. axis
    c. major
    d. minor
15. An object is situated at normal reading distance (i.e., −40 cm away from the lens.) If this lens has a power of −2.25 D, with what vergence will the light leave the lens?
    a. +2.25 D
    b. −0.25 D
    c. +0.25 D
    d. −4.75 D
16. A crown glass lens surface has a front-surface power of −5.00 D in air. What power does the lens surface have in water? (Index of crown glass = 1.523; index of water = 1.333.)
    a. −1.82 D
    b. −l.94 D
    c. +1.94 D
    d. −0.02 D
17. F_1 of a lens is +3.25 D, and F_2 is +3.25 D. The lens may be said to be:
    a. biconvex.
    b. meniscus.
    c. equiconvex.
    d. both a and c.
    e. both b and c.
18. If $F_1 = +8.00$ D and $F_2 = -8.00$ D, the lens is:
    a. equiconvex.
    b. equiconcave.
    c. planoconvex.
    d. biconvex.
    e. meniscus.
19. A − 2.00 D thin lens having a front-surface power equal to +6.00 D could be described as:
    a. equiconcave.
    b. biconvex.
    c. meniscus.
    d. planoconcave.
    e. planoconvex.
20. In the transposition process, which of the following is (are) *incorrect*?
    a. Subtract the sphere from the cylinder value to obtain the new sphere value.
    b. Change the sign of the cylinder (plus to minus, minus to plus).
    c. Change the axis by 90 degrees.
    d. None of the above.
21. Transpose the following prescription into plus cylinder form: +3.50 − 1.25 × 012
    a. +2.25 + 1.25 × 012
    b. +2.25 + 1.25 × 102
    c. +4.75 + 1.25 × 012
    d. +4.75 + 1.25 × 102
22. Transpose the following prescription into crossed-cylinder form: −0.50 + 1.00 × 075
    a. +0.50 × 165 / +1.00 × 075
    b. −0.50 × 165 / +1.00 × 075
    c. +1.00 × 075 / −1.00 × 165
    d. −0.50 × 165 / +0.50 × 075
    e. −0.50 × 075 / +0.50 × 165
23. A power cross has a power of −4.00 D in the 90-degree meridian and −1.00 D in the 180-degree meridian. How would this lens be written in minus cylinder form?
    a. −4.00 − 1.00 × 180
    b. −3.00 − l.00 × 090
    c. −4.00 − 3.00 × 080
    d. −1.00 − 3.00 × 180
24. What is this crossed cylinder prescription when written in minus cylinder form?
    +l.25 × 165 / −3.00 × 075.
    a. +1.25 − 4.25 × 165
    b. −2.75 − 3.00 × 075
    c. −3.00 − 1.25 × 075
    d. −2.75 − 1.25 × 165
    e. +1.25 − 4.25 × 075

25. What is the spherical equivalent for a spherocylinder lens with a power of $-6.00 - 1.00 \times 180$?
    a. −5.50 D
    b. −6.50 D
    c. −6.00 D
    d. −7.00 D
    e. −7.50 D

Challenge Question

26. Two thin lenses in air are separated by a distance of 80 cm. Both lenses have a power of +5.00 D. An image point formed by the first lens becomes the object point for the second. If an object is −40 cm from the first lens, where will the image point for the second lens be?
    a. +40 cm to the right of the second lens
    b. +13.33 cm to the right of the second lens
    c. −66.67 cm to the left of the second lens
    d. +28.57 cm to the right of the second lens

13

Lens Curvature and Thickness

CATEGORIES OF OPHTHALMIC LENSES

Ophthalmic lenses may be divided into the following three broad categories:

- Single-vision lenses
- Segmented multifocal lenses
- Progressive addition lenses

Single-Vision Lenses

Single-vision lenses are the most basic type of lens. These lenses have the same power over the entire surface of the lens. Single-vision lenses are used when the same optical power is needed for both distance and near vision. They are also used when a person requires no prescription for distance but needs reading glasses. Whenever possible, single-vision lenses are edged from lenses kept in stock at the laboratory. Because these lenses are optically finished to the correct power on both the front and back surfaces, they are called *finished lenses*. Finished lenses are also referred to as *uncuts* because they have not yet been "cut" to the correct shape and size (Figure 13.1, *A*). When single-vision lenses are in uncut form, they do not require that a surface power be ground onto the lens. These lenses may be kept in stock and are often called *stock single-vision lenses*.

A stock single-vision uncut lens is less expensive than a custom surfaced lens. However, if the stock lens is too small for the frame or has especially high powers or prism, then a stock single-vision lens will not work. Instead, the lens must be produced in the surfacing section of the optical laboratory. The surfacing laboratory puts surface power on the lens. They start with a lens having only one surface that is ready to use, or "finished." This finished surface is almost always the front surface. The laboratory must grind and polish the second surface to the required power. A lens with only one of the two surfaces finished is called a *semifinished* lens because it is only half finished. The prefix *semi-* means half (see Figure 13.1, *B*).

Neither finished uncut nor semifinished lenses have been edged. Before a lens has been edged, it is called a *lens blank*.

Segmented Multifocal Lenses

Segmented multifocal lenses have more than one power. Each power is located in a distinct area of the lens clearly bordered by a visible demarcation line. When two different areas exist, the lens is called a *bifocal lens* (Figure 13.2, *A*). When three areas exist, the lens is called a *trifocal lens* (see Figure 13.2, *B*). (Note: There are a few exceptions. For example, a lens with a near segment at the bottom and a second near segment at the top will have three sections, but it is not a trifocal lens—it is a double segment occupational lens.)

Multifocal lenses may be created in one of several ways. Here are the two ways most often used:

1. Multifocal lenses may be individually ground and polished to power by a surfacing laboratory from a semifinished lens blank.
2. Multifocal lenses may be individually cast molded to the prescribed power. Cast molding creates the lens from a liquid resin material. It is the same process used to make both plastic semifinished lenses and stock single-vision plastic lenses. Cast molding multifocal lenses to power skips the semifinished lens stage. Cast molding to power may be done by a larger wholesale facility or, if equipment is available, on a small scale in conjunction with a finishing (edging) laboratory.

Progressive Addition Lenses

Progressive addition lenses are used as an alternative to a segmented multifocal lens. They have distance power in the upper half of the lens. Lens power gradually increases as the wearer looks down and inward to view near objects.

Progressive addition lenses may be prepared for the finishing laboratory in the same way as segmented multifocal lenses. It may also be produced through a process called *digital* or *free-form surfacing*. If this process is used, it is possible to start with a lens blank without progressive optics already in place. Instead, the progressive optics are produced during the surfacing process.

BASE CURVES

Single-Vision Lens Curves

In constructing an ophthalmic lens, one of the lens curves of one surface becomes the basis from which the other curves are determined. This beginning curve on which the lens power is based is called the *base curve*. In single-vision prescription ophthalmic lenses, the base curve is always found on the front surface.

- ***For spherical lenses:*** In the case of spherical lenses, the front sphere curve is the base curve.
- ***For plus cylinder form spherocylinder lenses:*** If the lens is in plus cylinder form, there are two curves on the front. The base curve is the weaker, or flatter, of the two curves. The other curve becomes the *cross curve* (Figure 13.3). The back-surface curve is quite naturally referred to as the *sphere curve* since it only has one curve and is spherical.
- ***For minus cylinder form spherocylinder lenses:*** If the lens is in minus cylinder form, the front spherical curve is the base curve. The weaker back-surface curve is known as the *toric base curve;* the stronger back-surface curve is known as the *cross curve* (Figure 13.4). Optical laboratories refer to the toric base curve of a minus cylinder form lens as the *back base curve*. (On a plus cylinder form lens, the base curve and the toric base curve are the same curve.) Because of changes in the way single-vision lenses are manufactured, practically all single-vision lenses are now made minus cylinder in form.

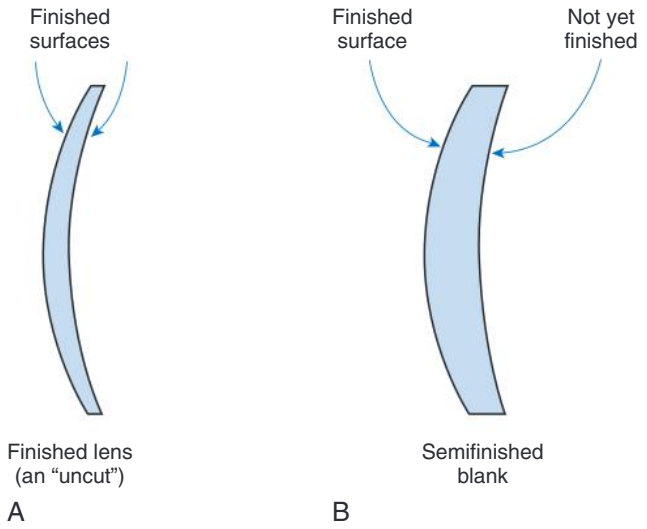


Figure 13.1 **A**, A finished lens is also referred to as an *uncut*. Most single-vision lenses are premanufactured to power as finished lenses and are referred to as *stock single-vision lenses*. **B**, Most any type of lens of any material may be made beginning with a semifinished lens.

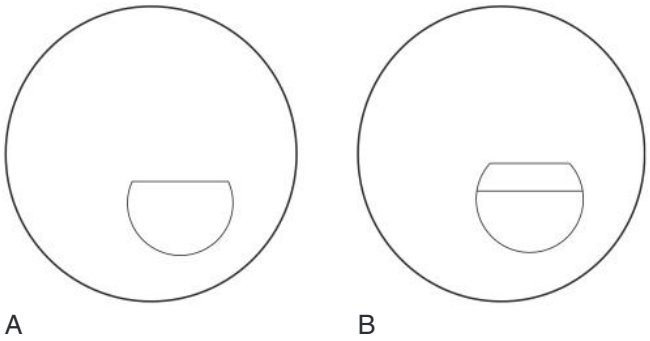


Figure 13.2 When a lens has a different power for near vision than distance vision, the lens area is divided between distance and near powers. **A**, A segment area for near vision is placed within the distance power lens. A lens with two different powers is a bifocal lens. **B**, Two segment areas are included: one for intermediate viewing and one for near viewing. This type of lens is a trifocal lens. Both lenses are flat-top-style multifocal lenses.

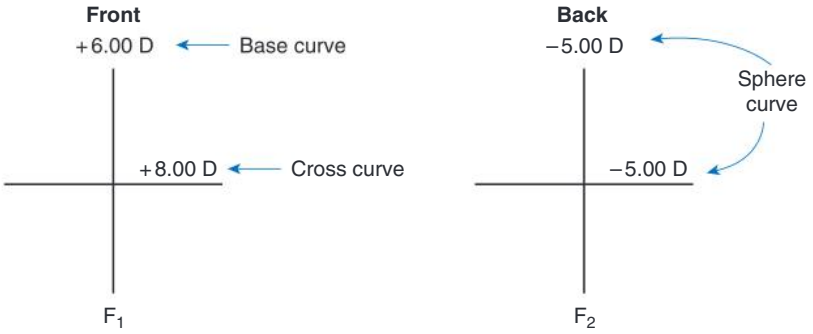


Figure 13.3 The base curve of a plus cylinder form single-vision lens is the weaker curve on the front surface.

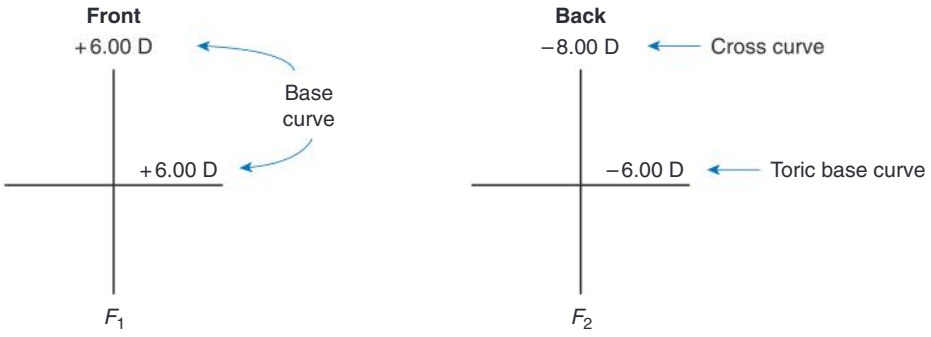


Figure 13.4 For a minus cylinder form single-vision lens, the base curve is the front sphere curve.

Example 13.1

A lens has a power of +1.00 + 2.00 × 090. If a base curve of +6.00 D were chosen, what front and back curves would be used?

Solution

The way to solve this is summarized in Box 13.1. We will solve the example problem by following the steps listed for plus cylinder form lenses.

1. A series of power crosses should be drawn. The first power cross is for the front surface, the second power cross for the back surface, and the third power cross for the total lens power. All initially given data should be entered on the power crosses. Here is how it is done.
2. The total lens power can be placed on the last of the three power crosses. This is the F_T, or total lens power cross shown in Figure 13.5, *A*. The sphere power (+1.00) will correspond to the 90-degree axis meridian because there is no

cylinder power in the cylinder axis meridian. This means that when entering spherocylinder lens power on a power cross, always enter the sphere power on the axis meridian. To find the power in the other meridian, simply add the cylinder power to the sphere power. In this case, we add a +2.00 to a +1.00 and get +3.00.

3. Now we can enter the base curve on the front surface. This is where it could get confusing. Because the cylinder power is on the front, on which meridian should the +6.00 D base curve be written? Here's how to find out. The base curve is, by definition, the *weaker* of the two front curves. This means that the base curve will correspond to the meridian, having the least plus power. In the example, we look at the powers on the last power cross and find that the least plus is in the 90-degree meridian. Therefore, the +6.00 D base curve is entered on the first surface (F_1) power cross at 90, as shown in Figure 13.5, *A*.
4. Now both F_1 at 180 and F_2 may be calculated by simple algebra. If F_1 at 90 is +6.00 D and F_T at 90 is +l.00 D, then

$$F_{1(90)} + F_{2(90)} = F_{T(90)}$$

In this example

$$+6.00\,\text{D} + F_{2(90)} = +1.00\,\text{D}$$
$$F_{2(90)} = +1.00\,\text{D} - 6.00\,\text{D} = -5.00\,\text{D}$$

The value −5.00 D may now be entered on the power cross at $F_{2(90)}$.

5. Since F_2 is spherical, not only is $F_{2(90)}$ −5.00 D in power, but so is $F_{2(180)}$.
6. This leaves only the cross curve as an unknown. This can be solved in either of two ways. The first is to use the system:

$$F_{1(180)} + F_{2(180)} = F_{T(180)}$$

which gives

$$(F_{1(180)}) + (-5.00\,\text{D}) = (+3.00)$$

Transposed, this is the same as:

$$(F_{1(180)}) = (+3.00\,\text{D}) - (-5.00\,\text{D})$$
$$= (+3.00\,\text{D}) + (5.00\,\text{D})$$
$$= +8.00\,\text{D}$$

7. We can check our work by using a second method of solving this problem. We see that the power of the cylinder is 2.00 D. Knowing this and realizing that the entire cylinder is on the front curve, it becomes apparent that the cross curve must be 2.00 D stronger than +6.00 D, which results in +8.00 D. Since this is the same value we found in step 6, the answer checks.

BOX 13.1 How to Find Lens Curves If Lens Power and Base Curve Are Known

Finding lens curves in plus cylinder form

1. Make front-surface, back-surface, and total lens power crosses.
2. Put the total lens power on the power cross.
3. Locate the base curve meridian. (Look on the F_T power cross. Find the least plus meridian. If the front surface has plus power, this least plus meridian will correspond to the base curve meridian on the front surface.)
4. Find the back curve power for that same meridian.
5. The other back-surface meridian will have the same power.
6. Find the front cross curve power from the total power and the back-surface power ($F_1 + F_2 = F_T$).
7. Check for cylinder accuracy on the front surface to be sure you have chosen the correct base curve meridian.

Finding lens curves in minus cylinder form

1. Make front-surface, back-surface, and total lens power crosses.
2. Put the total lens power on the power cross.
3. Put the base curve on both meridians of the front-surface power cross.
4. Algebraically find the back-surface curves ($F_1 + F_2 = F_T$).

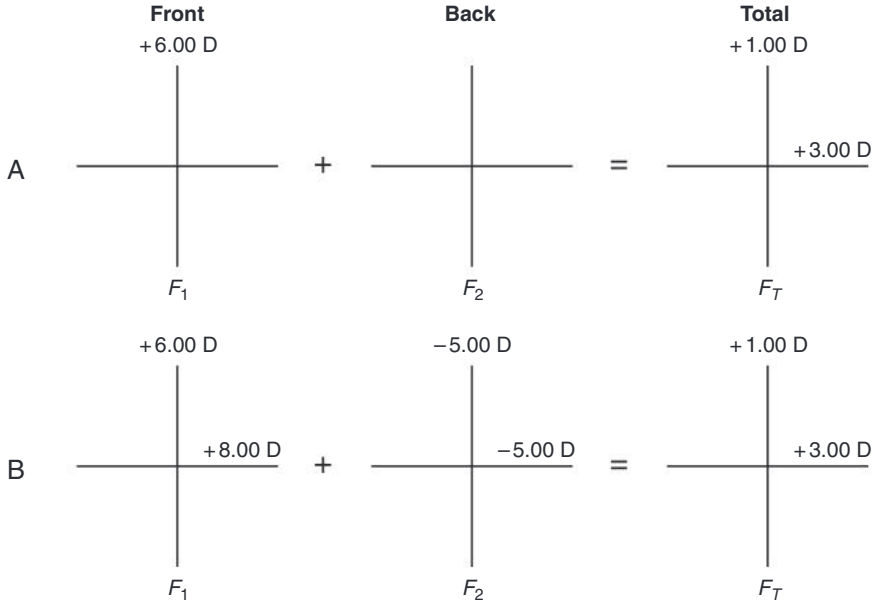


Figure 13.5 For plus cylinder form lenses, to find the unknown curves, first enter the known values **(A)**. The base curve can only go on the 90-degree meridian for this lens because the weaker power is in the 90-degree meridian. The remaining curves **(B)** may be found by algebraic additions. The base curve (and toric base curve) is +6.00 D. The cross curve is +8.00 D. The sphere curve is −5.00 D.

Example 13.2

If a lens has a power of $-1.50\ -1.00 \times 090$ and the lens is to be made in minus cylinder form, what front and back curves would be used if a base curve of +5.00 D were chosen?

Solution

The way to solve this minus cylinder base curve problem is also summarized in Box 13.1 and will be solved using the steps listed there for minus cylinder form lenses.

1. The three power crosses are drawn.
2. Now enter the prescription lens power on the last, or total, lens power cross. The sphere power of −1.50 is entered on the 90-degree meridian. This is because the 90-degree meridian is the cylinder axis meridian. There is no power contributed by the cylinder because a cylinder has zero power in its axis meridian. Only the sphere power shows up in the axis meridian of a spherocylinder lens. Now, the power in the 180-degree meridian is found by adding the cylinder power to the sphere power.

$$(-1.50) + (-1.00) = (-2.50)$$

3. The base curve is given as +5.00 D. This +5.00 D power is entered on both curves (in other words, in both meridians) of the front-surface power cross. This is because the lens is a minus cylinder form lens and the front curve is spherical, having the same power in all meridians (Figure 13.6).
4. Lastly, we find the second surface powers algebraically. For the 90-degree meridian this is:

$$(+5.00) + (F_{2(90)}) = (-1.50)$$
$$(F_{2(90)}) = (-1.50) - (+5.00)$$
$$(F_{2(90)}) = -6.50\text{D}$$

For the 180-degree meridian, we find

$$(+5.00) + (F_{2(180)}) = (-2.50)$$
$$(F_{2(90)}) = (-2.50) - (+5.00)$$
$$(F_{2(90)}) = -7.50\text{D}$$

The toric base curve is the weaker of the two curves. The weaker of the two curves is the −6.50 D curve in the 90-degree meridian. The cross curve is "across" from the base curve. It is the −7.50 D curve in the 180-degree meridian.

Segmented Multifocal Lens Base Curves

The base curve of a segmented multifocal lens is on the same side of the lens as the segment. If the bifocal or trifocal segment is on the front, so is the base curve. If the segments are on the back, the base curve will be on the back as well, contrary to single-vision lenses. Because a toric surface will not be ground on the same side as the multifocal segment, the base curve is a sphere curve.

Progressive Lens Base Curves

When progressive addition lenses are delivered to the optical laboratory as semifinished blanks, like segmented multifocals, the expected location of the base curve of a progressive edition lens follows the same pattern. The base curve will be on the same side as the progressive optics are found. The manufacturer defines what the value of the base curve is for a given lens. It should be noted that checking the base curve of a progressive addition lens with a lens clock may not be straightforward. Because of the variation in curvature across the lens surface, even in the distance portion of the lens, finding a stable area to obtain a consistent reading may not be possible. The reading may be close but variable.

With the advent of digital surfacing, progressive optics can be created during the surfacing process and placed on the front or back of the lens or be split between the front and back of the lens. Keep in mind that the manufacturer defines the base curve, and dispensers would do well to follow the manufacturer's pattern of assigning base curves to their lenses.

MEASUREMENT OF LENS CURVATURE

When ordering a replacement lens or supplying the wearer with a duplicate second pair of glasses sometime after the initial order, one factor in wearer acceptance of the new glasses is consistent duplication of base curves. A change in base curve will change the way peripherally

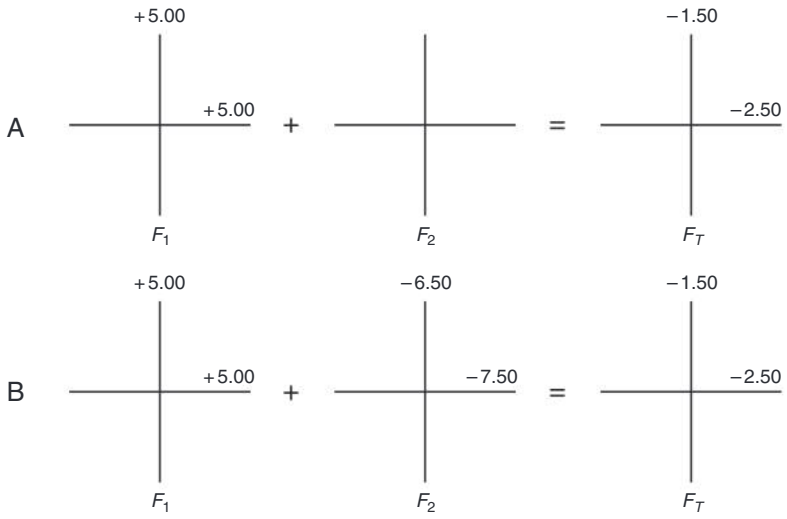


Figure 13.6 For minus cylinder form lenses, enter the known values on the power crosses first **(A)**. Then calculate the unknown values **(B)**. The base curve (and sphere curve) is +5.00 D. The toric base curve (sometimes called the *back base curve*) is −6.50 D. The cross curve is −7.50 D.

viewed objects are perceived, even though lens power may be identical. To measure a preexisting lens curve for accurate duplication or verification, a *lens clock* (sometimes referred to as a *lens measure*) is used (Figure 13.7).

The Lens Clock

The lens clock operates on the principle of *sagittal depth*. The sag formula is the height or depth of a given segment of a circle (Figure 13.8). If both the sagittal depth of a lens surface and the index of refraction of the lens material are known, the surface power may be calculated.

The lens clock has three "legs," or points of contact with the lens surface. The outer two are stationary, and the center contact point moves in and out. The vertical difference between the positions of the two outer contact points compared to the position of the center contact point is the sagittal depth for the arc of a circle. This circle can be thought of as having a chord, the length of which is the distance between the outer contact points of the lens clock (Figure 13.9).

Figure 13.7 A lens clock may use direct plus and minus scales as shown here or an outer minus scale for concave surfaces and an inner plus scale for convex surfaces.

The lens clock does not have a scale showing a direct measure of the sagittal depth but rather shows a dioptric value for the surface power. This power is based on an assumed index of refraction of 1.53. (Most tools found in a U.S. optical laboratory are based on an assumed index of 1.53.) The power shown on the lens clock is obtained by using the sagittal depth of the surface.

The Sagittal Depth Formula

Steps for finding the dioptric value for a lens surface begin with a geometric construction as shown in Figure 13.9. We need to know *r,* the radius of the circle, to find the front- or back-surface powers of a lens (F_1 or F_2).

From the geometry of right triangles, the triangle FGC has a relationship between its three sides that, because of the Pythagorean theorem, can be written as:

$$y^2 + (r - s)^2 = r^2$$

This is the same as:

$$y^2 + r^2 - 2rs + s^2 = r^2$$

By transposition:

$$y^2 + s^2 = r^2 - r^2 + 2rs$$

And again by transposition:

$$\frac{y^2 + s^2}{2s} = r$$

and

$$r = \frac{y^2}{2s} + \frac{s^2}{2s}$$

giving one form of an equation referred to as the *sagittal depth,* or *sag formula* (see Box 13.2).

$$r = \frac{y^2}{2s} + \frac{s}{2}$$

Once *r* is determined using the sag formula, then the Lensmaker's formula for surface power may be used to solve for F_1 or F_2 in air.

$$F_1 = \frac{n' - n}{r_1} = \frac{n_{lens} - 1}{r_1}$$

$$F_2 = \frac{n' - n}{r_2} = \frac{1 - n_{lens}}{r_2}$$

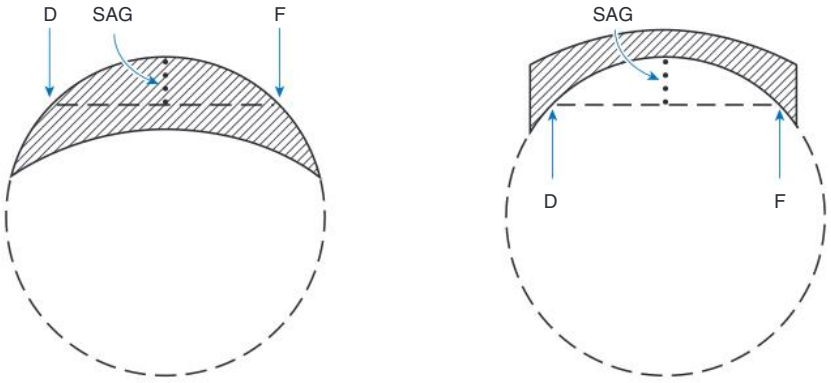


Figure 13.8 The sagittal (*SAG*) depth or height of the chord of a circle is shown as it applies to lens surface measurements. The chord of the circle is represented by line DF.

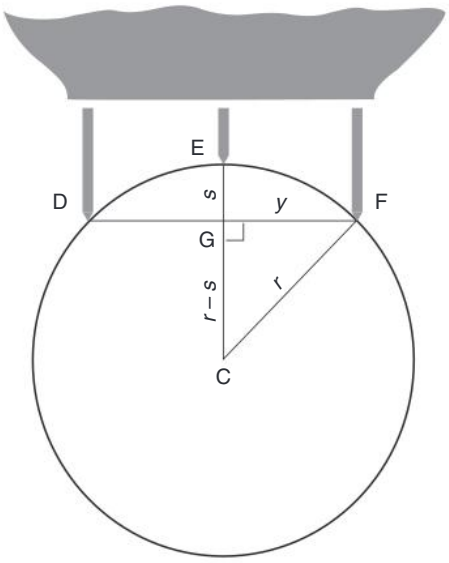


Figure 13.9 A lens clock works by mechanically determining the sagittal depth of a chord, the length of which is equal to the distance between the outer contact points of the lens clock.

BOX 13.2 The Sag Formula

The sag (sagittal depth) formula may be written in two different ways. When needing to know the radius of curvature when sagittal depth (s) and the semi-diameter of the chord (y) is known, the formula used is:

$$r = \frac{y^2}{2s} + \frac{s}{2}$$

This way of writing the sag formula is often associated with the lens clock (lens measure).

The second way of writing the sag formula is as follows:

$$s = r - \sqrt{(r^2 - y^2)}$$

Both formulas are the same but are algebraically transformed to be most appropriate, depending on whether we are wanting to find the radius of curvature of a surface or the sagittal depth of a surface.

This second form is used later in the chapter when lens thickness is discussed.

Remember, both are really the same formula, just written in different forms.

A lens clock is calibrated for an index of 1.530, which becomes the n of the lens value in the previous formulas. (Crown glass material has an index of 1.523. When used on crown glass lenses with low surface powers, the lens clock still gives fairly accurate surface power results. However, most lenses are not glass, but plastic, and have a variety of different refractive indices.)

So

$$F_1 = \frac{1.530 - 1}{r_1}$$

and

$$F_2 = \frac{1 - 1.530}{r_2}$$

For now we will ignore the lens clock and its assumed 1.53 index and just use sagittal depth and the Lensmaker's formula to find lens surface power.

Example 13.3

A certain glass lens of index 1.523 has a convex spherical front surface. The sag formula of the front surface is 1 mm for a chord whose length is 20 mm. What is the power of the front surface?

Solution

Using the sag formula,

$$r = \frac{y^2}{2s} + \frac{s}{2}$$

we know that

$$y = \frac{\text{Chord length}}{2} = \frac{20\,\text{mm}}{2} = 10\,\text{mm}$$

and

$$s = 1\,\text{mm}$$

Substituting known values into the sag formula, we can find the radius of curvature of the surface.

$$r = \frac{y^2}{2s} + \frac{s}{2}$$

$$= \frac{10^2}{2(1)} + \frac{1}{2}$$

$$= \frac{100}{2} + \frac{1}{2}$$

$$= 50.5\,\text{mm or } 0.0505\,\text{m}$$

Now that we know r, it is possible to use the Lensmaker's formula to find the front-surface refractive power of the lens.

$$F_1 = \frac{n_{\text{lens}} - 1}{r_1}$$

$$= \frac{1.53 - 1}{0.0505}$$

$$= 10.36\,\text{D}$$

The front-surface power of the lens is +10.36 D.

Using the Lens Clock to Find the Nominal Power of a Lens

Remember, the nominal power of a lens is the sum of the front and back surface powers. Nominal lens power ignores the effect that lens thickness may have on lens power. Nominal lens power may not be the power we get when measuring the lens with a lensmeter, because the thickness of the lens may influence that result.

Because it is possible to use a lens clock to find lens surface values directly for materials at or near an index of 1.53, it is also possible to use a lens clock for finding the nominal or approximate power of such lenses. An example of a lens material with an index of 1.53 would be the plastic material Trivex.

Here is an example of finding the nominal power of a lens. If a spherical lens has a measured front curve (F_1) of +6.00 D and a measured back curve (F_2) of −4.00 D, then the nominal power of the lens will be +2.00 D.

Not all lenses are spherical. This makes it necessary to check more than one lens surface meridian for differences in power. To do this, hold the lens clock such that the center contact point of the lens clock is at the center of the lens and is perpendicular to the lens surface

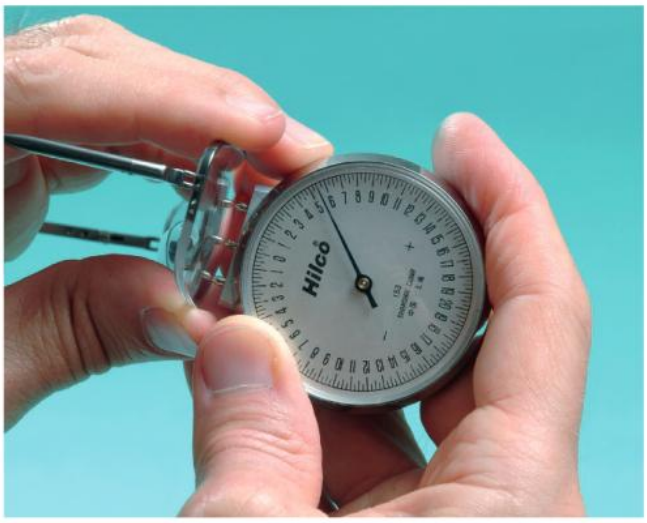


Figure 13.10 A lens clock is held perpendicular to the lens surface with the center contact point at the optical center. Tilting of the lens clock away from perpendicular results in a variation in the measured power.

(Figure 13.10). The lens clock is rotated around the center contact point. Note: There is a good possibility that the lens surface may be scratched by rotating the lens clock on the surface of the lens. Instead of just rotating the lens clock on the surface, it is advisable to alternately lift and reposition the lens clock instead. If the indicator on the lens clock dial reads the same in all meridians, the surface is spherical. The spherical surface value is as shown on the lens clock. If the indicator shows a changing value, the surface is toric with two separate curves. The values of these curves are indicated when the lens clock shows its maximum and minimum values. The orientation of the three contact points on the lens at maximum and minimum readings corresponds to the major meridians of lens power.

Example 13.4

When rotating the lens clock on the front surface of a crown glass lens, it is found that all meridians read +6.50 D. On the back surface, if the three contact points are horizontally aligned exactly along the 180-degree meridian, a maximum value of −7.50 D is found. When the three contact points are oriented in the vertical (90-degree) meridian, a minimum value of −6.00 D is found. What is the nominal power of the lens? Is the lens made in plus cylinder form or minus cylinder form?

Solution

The lens clock has found the major meridians of the lens. The values found should be transferred directly to power crosses for calculation of the total nominal lens power as shown in Figure 13.11. Add the 90-degree meridians of the front and back surfaces together to find the total power in the 90-degree meridian. Then do the same for the 180-degree meridian.

Using methods previously discussed, the total lens power may be taken from the final power cross and written in one of the three possible forms of prescription writing. These powers are:

1. +0.50 − 1.50 × 090
2. −1.00 + 1.50 × 180
3. +0.50 × 180 / −1.00 × 090

Because the toric surface is the back surface, the lens is a minus cylinder form lens.

Use of the Lens Clock With Multifocal Lenses

When the lens clock is used on a segmented multifocal lens, positioning of the contact points depends on lens construction. Multifocal lenses may be fused or one piece.

The *fused* multifocal segment uses glass of a different refractive index from that in the rest of the lens. The junction between distance and near portions is visible but cannot be felt since the glass segment is fused into the lens such that there is no change in lens surface curvature. A lens clock may, therefore, be used on the lens surface just like it would be for a single-vision lens. The reading will indicate only the surface power for the main lens. It does not read segment power.

A *one-piece* multifocal lens construction uses the same lens material for distance and near portions. Power differences between distance and near portions are brought about by a change in lens curvature. One-piece bifocals may be identified by either a ledge or by a change in the surface curve. The change may be felt by rubbing the finger over the juncture. In this case, to determine lens surface power for the main lens accurately, none of the three contact points may rest on the segment portion. To measure a one-piece bifocal lens, the lens clock is placed on the lens with all three contact points horizontally positioned in the center of the lens and above the multifocal line.

Why Measured Base Curves Do Not Always Come Out as Expected

When using a lens clock to measure the base curve of a lens, the values measured do not always come out the same as the manufacturer's stated value. A semifinished glass lens may arrive at the optical laboratory with a base curve of +8.25 D marked on the box. But when the front lens surface is measured, it may be slightly less than +8.25 D. Or a plastic lens could be marked as having a base curve of +10.25 D but measure as +10.50 D. Some assume that the lens clock is inaccurate; others assume that variations are due to differences in the index of refraction of the lens and the lens clock scale. Neither assumption is correct.

The real reason for the mismatch stems from the fact that there are several different front-surface lens curve terms used to describe the same lens surface curve. These terms are:

1. The nominal base curve
2. The true base curve (or so-called true power)
3. The refractive power

The Nominal Base Curve

An historical perspective for crown glass lenses. The *nominal base curve* was originally established as a reference number for the convenience of the optical laboratory when used for crown glass lenses. When low-powered crown glass lenses had their surfaces ground to power without the help of computerized lens surfacing programs, the correct back curve was found by subtracting the front surface from the needed lens power. For example, if the lens is supposed to have a power of +1.25 D and the base curve of the lens is +6.50, then the back-surface curve should be:

$$+1.25 - 6.50 = -5.25\,\text{D}$$

As the plus power of the lens increases, however, so does its thickness. Because of increased thickness, simple subtraction will not work. To make it possible for laboratory personnel to continue using the same simple calculation, lens manufacturers changed the front curve of the lens slightly to compensate for the effect of increasing thickness; but they left the listed base curve as the same number. When this is done, the value of the base curve is not the real power of the surface. Thus, it is called the *nominal base curve.* (This is not to be confused with nominal lens power, which is the sum of the first and second surface powers.)

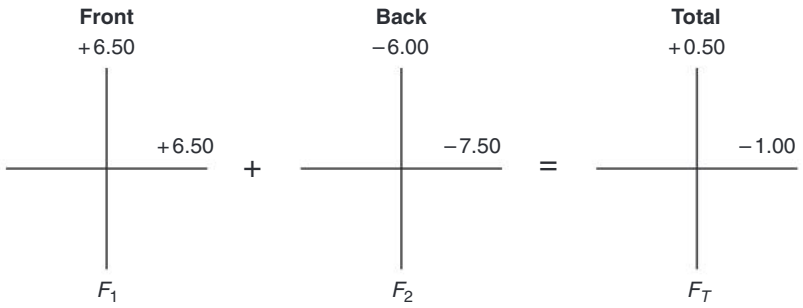


Figure 13.11 Lens clock readings may be transferred directly to power crosses for lens power calculation.

Plastic lens nominal base curve. With plastic lenses, the base curves vary from their marked values for a different reason. Plastic lenses start out as liquid resin and are molded. When their surfaces cure during manufacture, once removed from the mold, the final curve of the surface may vary from the curve of the mold. Initially, it was difficult to predict the exact final lens curve value. Although the final curve of the lens after being removed from the mold is now predictable, the difference between the labeled base curve (the nominal base curve) of a plastic lens and measured base curve (the true base curve) remains.

True Base Curve ("True Power")

The so-called true base curve of a lens is the value of the front surface as measured using a lens clock. As counterintuitive as it may seem, synonyms for true base curve are "*true power*" and "*actual power*." The lens clock used in the United States for measuring surface curvature is calibrated for an index of 1.53. The *true base curve* is the 1.53 indexed value. Except for Trivex, which has an index of 1.53, and crown glass with an index of 1.523, most lens materials are not very close to the lens clock-calibrated value of 1.53. Because of differences in refractive indices, it is easy to see that the "true" base curve measured with a lens clock is unlikely to be the refractive power of the lens surface.

The Refractive Power of the Lens Surface

The *refractive power* controls what happens to light at the surface of the lens. It will be recalled that surface power is dependent on three factors. These are:

1. The refractive index of the lens surface
2. The refractive index of the media surrounding the lens
3. The radius of curvature of the lens surface for the front surface of the lens this refractive power is found using the Lensmaker's formula:

$$F_1 = \frac{n' - n}{r_1}$$

As previously stated, lens clocks are calibrated for lens material having a refractive index of 1.53. If a lens made from material of a different refractive index is used, compensation must be made if the surface refractive power is to be found using a lens clock.

Finding the Refractive Power of a Lens Surface Using a Lens Clock

To find the refractive power of a lens surface using a lens clock, the "true power" reading from the lens clock must be converted to refractive power. This is done with the help of the Lensmaker's formula shown previously.

When using the lens clock, we are indirectly determining the radius of curvature of the surface in question, regardless of its refractive index.

Example 13.5

The front surface of a lens is measured with a lens clock. The lens clock shows a value of +6.00 D based on an assumed index of 1.530. What is the radius of curvature of the lens surface?

Solution

The information given allows all terms of the Lensmaker's formula to be filled in except r_1.

$$F_1 = \frac{n' - n}{r_1}$$

$$+6.00 = \frac{1.53 - 1}{r_1}$$

Therefore,

$$r_1 = \frac{1.53 - 1}{+6.00}$$

$$= \frac{0.53}{+6.00}$$

$$= 0.0883$$

The lens surface has a radius of curvature of 0.0883 m.

Example 13.6

Suppose that instead of having an index of 1.530, the above lens material is CR-39 plastic with an index of 1.498. What front-surface refractive power does this lens have?

Solution

Again, the basic surface power equation may be used and the known values substituted to find the unknown value for $F_{1(\text{CR-39})}$.

$$F_{1(\text{CR}-39)} = \frac{n' - n}{r_1}$$

$$= \frac{1.498 - 1}{0.0883}$$

$$= 5.64\text{D}$$

The front-surface refractive power for the CR-39 lens is +5.64 D. Because the lens has a lower refractive index, the lens surface does not have as much refractive power as shown by the lens clock.

Using a Conversion Factor

It is possible to reduce the process of converting from lens clock readings to surface refractive power by using a formula-generated conversion factor. This is done as follows:

If, for the lens clock,

$$F_{(lens\ clock)} = \frac{1.53 - 1}{r}$$

then

$$r = \frac{0.53}{F_{(lens\ clock)}}$$

and if, for the surface of different index material,

$$F_{(new\ material)} = \frac{n' - 1}{r}$$

then

$$r = \frac{n' - 1}{F_{(new\ material)}}$$

Since both equations are referring to the same lens surface, then both r values are the same. As a result, we can combine the two equations, giving the following:

$$\frac{0.53}{F_{(lens\ clock)}} = \frac{n' - 1}{F_{(new\ material)}}$$

Transposing gives the refractive power for the new material.

$$F_{(new\ material)} = \frac{(n' - 1)F_{(lens\ clock)}}{0.53}$$

This means that, for any given lens material, we can substitute the refractive index of the new material for n' into the formula and obtain a conversion factor.

Example 13.7

What is the conversion factor for converting the lens clock reading to refractive power for a lens surface made from 1.586 polycarbonate material?

Solution

Substituting 1.586 for n' into the formula results in the following:

$$\begin{aligned} F_{(new\ material)} &= \frac{(n' - 1)F_{(lens\ clock)}}{0.53} \\ &= \frac{(1.586 - 1)F_{(lens\ clock)}}{0.53} \\ &= \frac{(1.586)F_{(lens\ clock)}}{0.53} \\ &= (1.106)F_{(lens\ clock)} \end{aligned}$$

The conversion factor is 1.106.

Example 13.8

Use the conversion factor for polycarbonate to find the surface refractive power for the front surface of a polycarbonate lens. The lens clock measures a "true power" of +8.12 D for the lens.

Solution

We use the conversion formula with the 1.106 conversion factor to find:

$$\begin{aligned} F_{(new\ material)} &= (1.106)F_{(lens\ clock)} \\ &= (1.106)(8.12) \\ &= +8.98\,\text{D} \end{aligned}$$

The surface of the lens is +8.98 D or, if rounded, +9.00 D of refractive power.

Using the Lens Clock to Find Lens Power for Lenses of Different Refractive Indices

If it is possible to use the lens clock to find front-surface refractive power, it is also possible to measure both front and back surfaces to find a nominal lens power. It should be noted that, for a thick lens, the lens power found may still not be exact. Remember, the lens power obtained by adding front and back surfaces is called the *nominal power* of the lens and should not be confused with the nominal base curve.

Example 13.9

A lens clock is used on the front and back surfaces of a lens. The front-surface value found is +2.00 D. The back-surface value measures −6.87 D in the 90-degree meridian and −6.00 D in the 180-degree meridian. The lens has an index of refraction of 1.66. What is the power of the lens expressed in minus cylinder form?

Solution

To answer the question, we first need a conversion factor.

$$\begin{aligned} F_{(new\ material)} &= \frac{(n' - 1)F_{(lens\ clock)}}{0.53} \\ &= \frac{(1.66 - 1)F_{(lens\ clock)}}{0.53} \\ &= (1.245)F_{(lens\ clock)} \end{aligned}$$

The conversion factor is 1.245.

Applying the conversion factor to the first surface, we find:

$$\begin{aligned} F_{(new\ material)} &= (1.245)(+2.00) \\ &= +2.49\,\text{D} \end{aligned}$$

Applying the conversion factor to the back surface in the 90-degree meridian results in:

$$\begin{aligned} F_{(new\ material)} &= (1.245)(-6.87) \\ &= -8.55\,\text{D} \end{aligned}$$

and in the 180-degree meridian we get:

$$\begin{aligned} F_{(new\ material)} &= (1.245)(-6.00) \\ &= -7.47\,\text{D} \end{aligned}$$

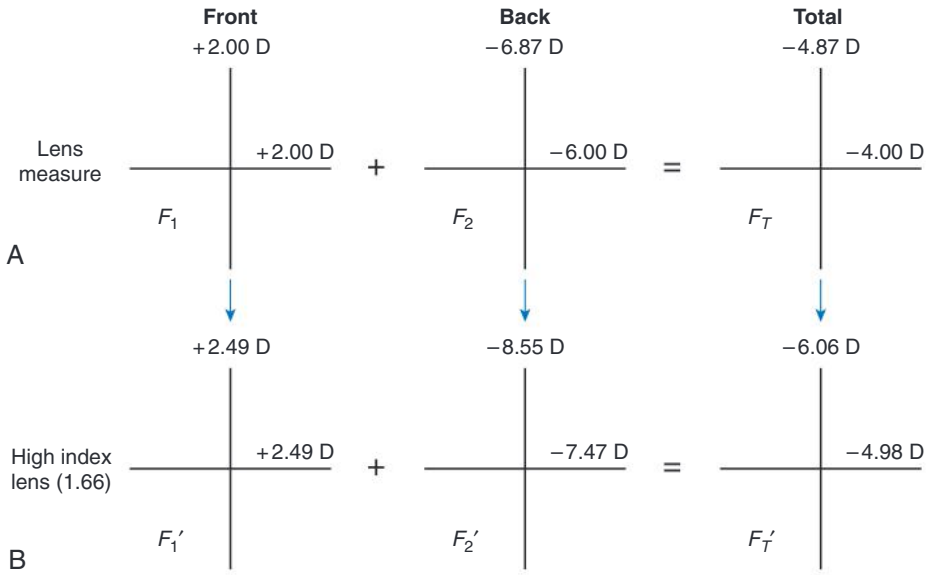


Figure 13.12 A lens clock is used on a lens having an index of refraction of 1.66. The lens clock readings for the front and back surfaces are entered on the first and second power crosses **(A)**. The actual lens power may be found in one of two ways. The first way is to correct both front- and back-surface powers for refractive index and then add them together. This is shown in the figure by converting the numbers for the front and back surfaces **(A)** and entering them on the power crosses directly below **(B)**. Then the new front- and back-surface powers **(B)** are added together and entered on the F_T' power cross **(B)**. The second, easier way to find actual lens power is to first add the original lens clock readings for the front and back surfaces together. This total is shown as the third F_T' power cross **(A)**. Then these values are corrected for index of refraction. The results are entered directly on the third F_T' power cross **(B)**.

Adding front- and back-surface powers together gives:

$$F_{Nominal} = F_1 + F_2$$
$$F_{90} = (+2.49) + (-8.55) = -6.06\text{D}$$
$$F_{180} = (+2.49) + (-7.47) = -4.98\text{D}$$

This is shown in Figure 13.12. Rounding to more realistic values gives −6.00 D in the 90-degree meridian and −5.00 D in the 180-degree meridian. In minus cylinder form, the lens power is written as:

$$-5.00 - 1.00 \times 180$$

The Compensated Power Method

It is possible to find the power of the lens by adding front- and back-surface lens-clock–measured values *before* multiplying by the conversion factor. This will save a step and give the same results.

In the previous example, adding together front- and back-surface lens clock values gives:

$$F_{Nominal} = F_1 + F_2$$
$$F_{90} = (+2.00) + (-6.87) = -4.87\text{D}$$
$$F_{180} = (+2.00) + (-6.00) = -4.00\text{D}$$

These two values are called *compensated powers.*[1] Multiplying the compensated powers (−4.87 D and −4.00 D) by the 1.245 conversion factor gives −6.06 D and −4.98 D in the 90- and 180-degree meridians, respectively. These are the same values as found by the first method. The logic of the process is shown by noticing the arrows drawn in Figure 13.12.

When to Specify Base Curve

There are certain situations in which base curve should be specified when ordering a prescription. These are:

- ***When replacing one lens in a pair:*** Base curve choices are made as a pair. When only one lens is ordered, the laboratory will not know what the other lens is if the old lenses do not accompany the order. And even if they do accompany the order, they might not be checked.
- ***When ordering an identically powered second pair:*** Base curve should also be specified when ordering an identically powered second pair of glasses when made from the same lens material. This second pair of glasses will be worn interchangeably with the first pair. The curve of a lens affects how shapes and straight lines appear. Two pair of glasses made using different base curves will cause shapes to distort differently. Some individuals are more sensitive to this than others. To prevent the possibility of difficulty when changing back and forth with different pairs of glasses, the safest policy is to keep the base curve powers of the two lens pairs as close to one another as possible.

When specifying a certain base curve, remember that semifinished lenses come in only so many base curves. Ordering, for example, a +8.00 base curve may result in one that is close but not exactly +8.00. American National Standards Institute (ANSI) Z80.1 Prescription Standards allow a base curve tolerance of ±0.75 D. To help in getting a lens with the exact same base curve, try ordering from the same optical laboratory that was used for the first pair. The brand of lenses they use is more likely to allow an exact match.

When Not to Specify Base Curve

There are some situations in which a base curve should not be specified so that the laboratory can pick the best base curve for the prescription ordered.

[1] An historical note: Before computer software programs became readily available, the optical laboratory used the compensated power concept to determine the back-surface powers needed to surface minus lenses. The ordered back vertex power was converted into a 1.53-based "compensated power." Then the correct 1.53-indexed surfacing tools were found by subtracting the 1.53-referenced front-surface power from the compensated power.

- ***Do not insist on matching the base curve of the new glasses to the wearer's previous lenses.*** Prescriptions change, and as the power of the lens changes to prevent unwanted lens aberrations, the power of the base curve should be expected to change, too. A base curve should not be expected to perpetually be the same for the life of the wearer.
- ***Do not request a flatter base curve to get a thinner, better-looking lens.*** Flattening a base curve will often make a plus lens look much better. It will usually reduce magnification, decrease thickness, and even reduce the weight a bit. However, there will be an increase in unwanted aberration in the periphery of the lens because of using a base curve that is not correct for the power of the lens.
- ***Do not change the base curve to solve ghost-image internal lens reflection problems.*** Before antireflection coatings were commonly used, one solution for getting rid of ghost images was to change the base curve. Changing the base curve will shift the size and location of those ghost images but will not drop them out like an antireflection coating will. Only use a base curve change to help with ghost images if an antireflection coating is not an option.
- ***Do not automatically steepen the base curve for people with long eyelashes.*** Instead, try to solve the problem of lashes touching the lens with a good frame selection. It is true that steepening the base curve by 2.00 D will give about 1.2 mm of extra lash clearance, but it will mean that optimal optics from a good base curve selection will be lacking.

ADDING CYLINDERS

Lenses can be added together. This is done routinely during the eye examination. Small spherically powered lenses are added to large spherically powered lenses. For example,

$$(+3.00\,\text{D sphere}) + (+0.25\,\text{D sphere}) = +3.25\,\text{D sphere}.$$

Sphere lenses are added to cylinder lenses, resulting in spherocylinder lens combinations, as with these two lenses.

$$(+3.00\,\text{D sphere}) + (\text{pl} - 1.50 \times 180\,\text{cylinder}) = (+3.00 - 1.50 \times 180)$$

In the same way that power crosses are used when adding front and back lens *surfaces* together to find total lens power, so also may power crosses be used as a help when adding two or more *lenses* together. To visualize how lens meridians add together for the sphere and cylinder lenses in the above example, see Figure 13.13.

Adding Cylinders Having the Same Axis or With Axes 90 Degrees Apart

Spheres and spheres may be added. Spheres and cylinders may be added as well. Although not as obvious initially, it is also the case that cylinders and cylinders may be added. Here, we will be looking at adding cylinders with axes that are either the same or 90 degrees away from each other.

Example 13.10

What is the resulting sum of two cylinder lenses, both having a power of pl − 2.00 × 180?

Solution

To find the solution, make three power crosses with the first two adding to equal the third. Place the powers of the two cylinder lenses on the first two power crosses. Because both lenses are identical, they will look the same on the first two power crosses. The axis is 180, so there is zero power in the 180-degree axis meridian. The power is −2.00, so −2.00 is written on the 90-degree power meridian. This is shown in Figure 13.14.

Next, the powers in the 180-degree meridian are summed. Zero plus zero equals zero. Then the 90-degree powers are summed. (−2.00) + (−2.00) = (−4.00).

The resulting power cross may be written in minus cylinder form as pl − 4.00 × 180.

Example 13.11

We will now take the same two cylinder lenses, but with axes oriented differently, and sum them. What is the sum of a pl − 2.00 × 180 lens and a pl − 2.00 × 090 lens?

Solution

Again, placing these two lenses on power crosses helps in visualizing what is happening. The first lens has zero on the 180-degree meridian and −2.00 on the 90-degree meridian. The second lens has zero on the 90-degree meridian and −2.00 on the 180-degree meridian. When the two lenses are added together in each meridian, as shown in Figure 13.15, the result is a −2.00 D sphere.

Example 13.12

Add these two lenses to find the resulting spherocylinder lens.

pl − 1.25 × 090

pl − 2.25 × 180

Solution

Draw three power crosses, and enter the cylinder lenses shown above on the first two. This is shown in Figure 13.16. Sum the 90-degree meridians and then the 180-degree meridians. The result is a lens with a power of −1.25 −1.00 × 180.

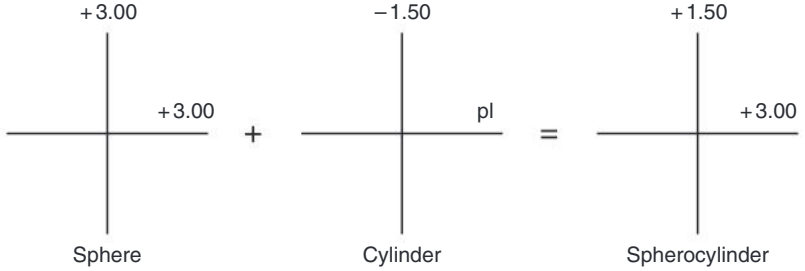


Figure 13.13 Power crosses allow a sphere and cylinder to be added together to form a spherocylinder.

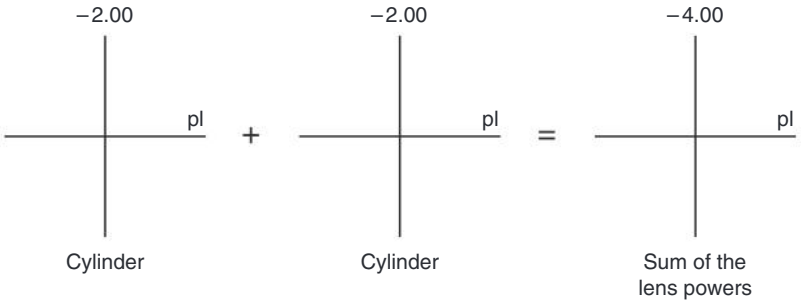


Figure 13.14 When two plano-cylinder lenses are placed together axis-to-axis, the resulting cylinder power is the sum of the cylinder powers.

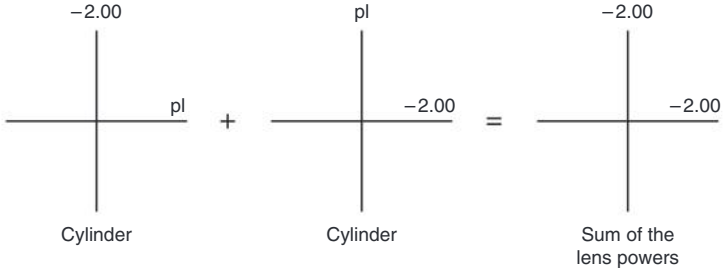


Figure 13.15 When two equal powered plano-cylinders are placed together with axes 90 degrees away from one another, the resulting lens is a sphere.

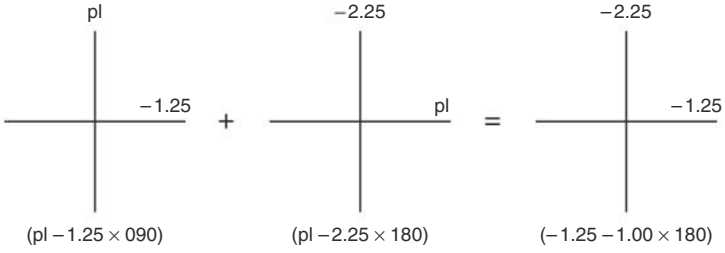


Figure 13.16 When two unequally powered plano-cylinders are placed together with axes 90 degrees away from one another, the result is a spherocylinder lens.

Jackson Crossed Cylinders

A *Jackson crossed cylinder* (JCC) is a lens used in the eye examination process to help in determining cylinder axis and cylinder power. It has plus power in one meridian and an equal and opposite amount of minus power in the other. All JCCs have a spherical equivalent power of zero. An example of a JCC is shown in Figure 13.17.

The power for a JCC lens is written as if the lens were two cylinders of equal and opposite powers using a plus/minus sign (±) in front of the dioptric power.

Example 13.13

What would a ±1.00 Jackson crossed cylinder (JCC) look like on a power cross? From what two plano-cylinders is it derived?

Solution

A ±1.00 JCC has a power of +1.00 in one meridian and −1.00 in the opposite meridian. Figure 13.18 shows what this could look like if the +1.00 were in the 90-degree meridian. It is the same as crossing two cylinders of equal and opposite value. In this case, these two cylinders would be:

pl + 1.00 × 180 / pl − 1.00 × 090

By flipping the cylinder over, using its handle positioned halfway between the major meridians of the JCC lens, the minus and plus powers trade places. When looking through first one orientation of the lens and then flipping the JCC by 90 degrees to the opposite orientation, exaggerated views through the opposing cylinders are seen. Exaggerating the differences makes it easier to know the answer to the familiar question asked during refraction, "Which (view) is better, one or two?"

Example 13.14

A ±1.00 Jackson crossed cylinder (JCC) is held so that the plus power is in the 90-degree meridian. This was the situation shown in Figure 13.18. A JCC lens can also be written as if it were an ordinary spherocylinder lens combination. If the power of a ±1.00 JCC lens were to be written as a spherocylinder lens combination in minus cylinder form, how would it be written?

Solution

If written in minus cylinder form, the meridian of highest plus or least minus is the sphere power. The difference between the two meridians is the cylinder power, and the axis location is the meridian of sphere power. Therefore, this ±1.00 JCC has a spherocylindrical power of +1.00 − 2.00 × 090.

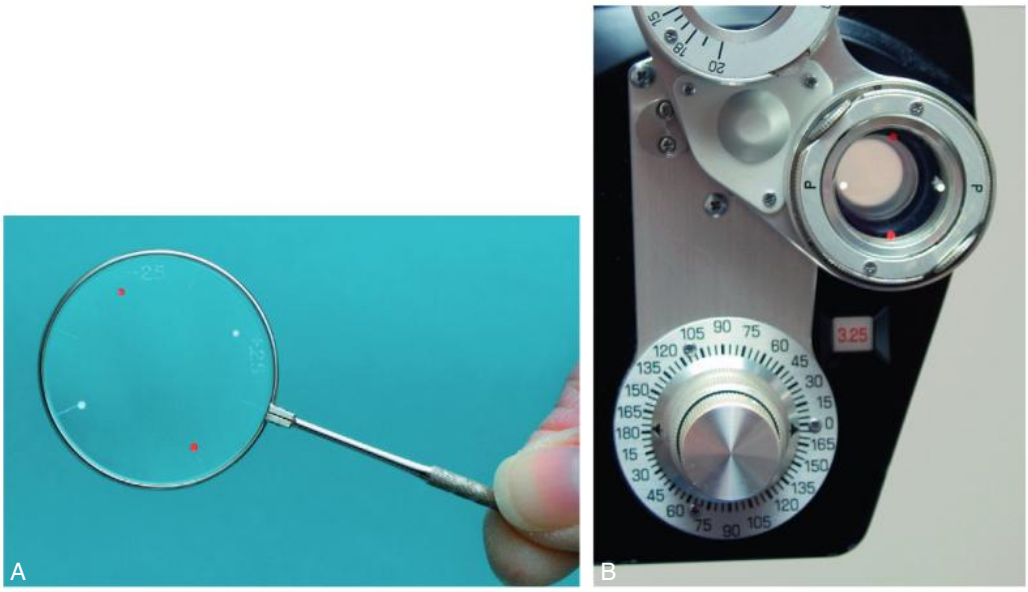


Figure 13.17 Jackson crossed cylinders (JCCs) are used during lens refraction to find cylinder power and cylinder axis. A hand-held JCC used during trial frame refraction is shown in **A**. A phoropter-mounted JCC is shown in **B**.

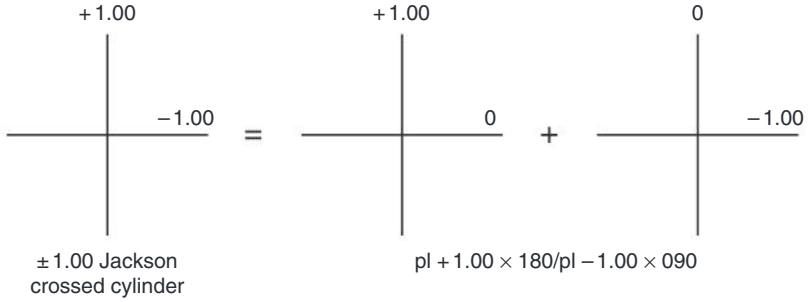


Figure 13.18 A ±1.00 Jackson crossed cylinder is the same as a plano +1.00 cylinder and a plano −1.00 cylinder with axes 90 degrees apart. If this particular lens were written as a spherocylinder lens, it would have a power of +1.00 −2.00 × 090.

Obliquely Crossed Cylinders

It is considerably harder to add two cylinders or spherocylinder lenses together when their axes are neither the same nor at 90 degrees away from one another but are crossed obliquely. For example, one may have an axis of 35, and another may have an axis of 65.

Obliquely crossed cylinders can occur clinically. From a spectacle lens standpoint, this happens when a person is wearing an existing pair of glasses and a refraction is done over the glasses. There may be a spherocylinder in the original glasses and a second spherocylinder lens combination in the overrefraction. These auxiliary lenses may be clipped to the wearer's glasses with a refracting cell to hold the lenses. From a practical standpoint, the easiest way to find the resultant combination is to take the wearer's glasses with the cell and auxiliary lenses in place to the lensmeter and simply read the total lens combination.

Another clinical situation occurs when a person is wearing a toric contact lens that contains a cylinder power. The power may not be quite right. The examiner refracts over the contact lenses. The overrefraction must be combined with the existing spherocylinder contact lens power to find the needed new contact lens power.

In doing an obliquely crossed cylinder calculation, there are three ways that are used to arrive at an accurate answer. These are:

- Use a graphical method.
- Use a formula method.
- Use an online calculator.

The graphical method is helpful in that it not only is able to furnish a usable answer but will also help in conceptually understanding how obliquely crossed cylinders interact to give a resultant spherocylinder lens power. It is the basis for the formula method. The formula method is complex but favored by those who love math. The formula method is the basis for online calculators.

This bears repeating—The graphical method is not necessarily something that will be done in practice (nor will the formula method, for that matter). However, understanding the workings of the graphical method is really helpful in understanding how two obliquely crossed cylinders or spherocylinders interact with one

another. The main emphasis is to understand what is happening conceptually.

The Graphical Method

The graphical method uses vectors to find the power and axis direction of the combined cylinder lenses. However, it is not exactly like normal vector problems. It requires some modification. The reason for this is because a cylinder of power −2.00 × 000 is not equal and opposite to a cylinder of power −2.00 × 180 degrees. If these are added together, the resulting cylinder would be −4.00 × 180. This is because axis 0 is the same as axis 180.

The two cylinder axis degree values that are opposite from a vector standpoint are 0 (or 180) and 090. In other words, if −2.00 × 000 and −2.00 × 090 are added, the cylinders cancel out. The result is a −2.00 D sphere. Therefore, if a problem like this is to be solved graphically using vectors, the cylinder axes need to be doubled.

With that in mind, here is a graphical method for finding the resulting power of two obliquely crossed plano-cylinders or spherocylinders.

1. Convert the two cylinders to be consistent with one another. In other words, both must be written as plus cylinders or both written as minus cylinders.
2. Construct a set of boxes for ease of calculation (Figure 13.19). Write the lens powers of the two spherocylinder lenses in the appropriate boxes.
3. Compute equivalent spheres for the two lenses and add them together, entering the sum in the "Equivalent box for C." (If two spherocylinder lenses are combined, the resulting lens has the same spherical equivalent as the sum of the spherical equivalents.)
4. Plot and construct vectors of the two cylinder values, and find the resulting vector sum and axis. Here's how it's done.
   a. Double the axes of the cylinders for vector drawing purposes. (This is because a cylinder axis of 090 is opposite from a cylinder axis of 180.)
   b. Draw the cylinder powers to scale as written, but draw the axis as doubled.
   c. Draw out the resultant vector and measure its length. This is the resultant cylinder power.
   d. Read off the angle of the new cylinder vector and divide by two. This value is the new cylinder axis.
5. Enter the new cylinder power and axis in the Spherical Equivalent box for C in Figure 13.19.
6. Take the spherical equivalent of the new cylinder power and *subtract* it from the equivalent sphere power found in Spherical Equivalent box for C. This gives the new sphere power of the resultant spherocylinder lens. *(Remember—If the lens is minus cylinder in power, you will be "minusing" a minus value. Two minuses make a plus!)*

Example 13.15

Use the graphical method just described to find the resultant spherocylinder lens power when these two obliquely crossed cylinders are combined.

pl − 2.00 × 180
−2.00 + 2.00 × 135

Solution

1. One lens is a minus cylinder, the other a plus cylinder. Converting them both to minus cylinders results in:

   pl − 2.00 × 180
   pl − 2.00 × 045

2. The lens powers are written in the box shown in Figure 13.20.
3. The spherical equivalent of pl −2.00 × 180 is −1.00 D sphere. This is also the spherical equivalent of the other lens. So −1.00 is entered into the first two Spherical Equivalent boxes for A and B. These are then added together and −2.00 is entered into the Spherical Equivalent box for C.
   a. To plot these Cylinder values, we need to double each axis. Doubling axis 180 gives 360. (Since axis 180 is the same as axis 0, this is the same as saying 0 doubled is 0.) Doubling axis 45 gives 90.
   b. The cylinder power vectors are entered at 0 and at 90, as shown in Figure 13.21. (When drawing cylinder powers, negative signs are ignored.)
   c. The new cylinder power is measured out to be 2.83. (Actually we cannot measure to this degree of accuracy, but we can be close.) So the cylinder power is −2.83.
   d. The new cylinder axis measures 45 degrees. We divide 45 by 2. This result of 22.5 degrees is the axis of the new cylinder.
4. The new cylinder power and axis values are written in section C of Figure 13.20.
5. Now we know everything except the new sphere power. Since we know the spherical equivalent of the new lens, we can find the sphere value by taking half of the new cylinder power and subtracting it from the spherical equivalent. In other words, if:

$$\text{Spherical equivalent} = \text{Sphere} + \frac{\text{Cylinder}}{2}$$

Figure 13.19 A template to help calculate the resultant of two obliquely crossed cylinder lenses.

	Sphere	Cylinder	Axis	Spherical equivalent
A	0.00	−2.00	180	−1.00
+				
B	0.00	−2.00	45	−1.00
= C	−0.58	−2.83	22.5	−2.00

Figure 13.20 The template for finding the result of two obliquely crossed cylinders crossed at a 45-degree angle.

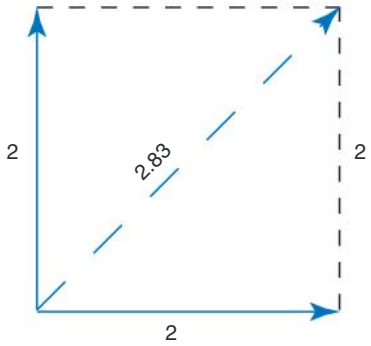


Figure 13.21 Graphically plotting two equally powered obliquely crossed cylinders:
For pl − 2.00 × 180, the axis is doubled and drawn at axis zero.
For pl − 2.00 × 045, the axis is doubled and drawn as 90.
The resultant power is −2.83 along the 45-degree meridian.
The resultant axis is $\frac{45}{2}$, or 22.5 degrees.

Then,

$$\text{Sphere} = \text{Spherical equivalent} - \left(\frac{\text{Cylinder}}{2}\right)$$

So, for the problem at hand,

$$\begin{aligned}\text{Sphere} &= \text{Spherical equivalent} - \left(\frac{\text{Cylinder}}{2}\right)\\ &= -2.00 - \frac{-2.83}{2}\\ &= -2.00 - (-1.42\,\text{D})\\ &= -0.58\,\text{D}\end{aligned}$$

The new spherocylinder lens power will be −0.58 −2.83 × 022.5.

Example 13.16

Use the graphical method to find the resultant spherocylinder lens power when these two obliquely crossed spherocylinder lenses are combined.

−1.00 − 2.00 × 020
−2.50 − 3.00 × 080

Solution

1. Since both these lenses have the same sign for the cylinder, neither needs to be converted.
2. The powers of these two lenses are entered into Figure 13.22.
3. Since

$$\text{Spherical equivalent} = \text{Sphere} + \frac{\text{Cylinder}}{2}$$

then, for the first lens

$$\begin{aligned}\text{Spherical equivalent} &= -2.00 + \frac{-2.00}{2}\\ &= -1.00 + -1.00\\ &= -2.00\,\text{D}\end{aligned}$$

And for the second lens,

$$\begin{aligned}\text{Spherical equivalent} &= -2.50 + \frac{-3.00}{2}\\ &= -2.50 - 1.50\\ &= -4.00\,\text{D}\end{aligned}$$

These are entered into the Spherical Equivalent boxes for A and B and then added together. The −6.00 D spherical equivalent sum is entered into the Spherical Equivalent box for C.

4a. The cylinder axes are doubled so that the first will be 40 and the second will be 160.
4b. The cylinder powers are left as is, and vectors are constructed as shown in Figure 13.23.
4c. The resultant vector is measured to be 2.64 units long.
4d. The axis read is 120 degrees. This value is divided by 2, making the new cylinder have a cylinder axis of 060 degrees.
5. The value −2.64 × 060 is entered into the Spherical Equivalent box for C in Figure 13.22.
6. The new sphere power is found as:

$$\begin{aligned}\text{Sphere} &= \text{Spherical equivalent} - \left(\frac{\text{Cylinder}}{2}\right)\\ &= -6.00 - \left(\frac{-2.64}{2}\right)\\ &= -6.00 - (-1.32)\\ &= -4.68\,\text{D}\end{aligned}$$

The new spherocylinder lens is then −4.68 −2.64 × 060.

	Sphere	Cylinder	Axis	Spherical equivalent
A	−1.00	−2.00	020	−2.00
+				
B	−2.50	−3.00	080	−4.00
= C	−4.68	− 2.64	060	−6.00

Figure 13.22 The template with two obliquely crossed spherocylinder lens powers entered.

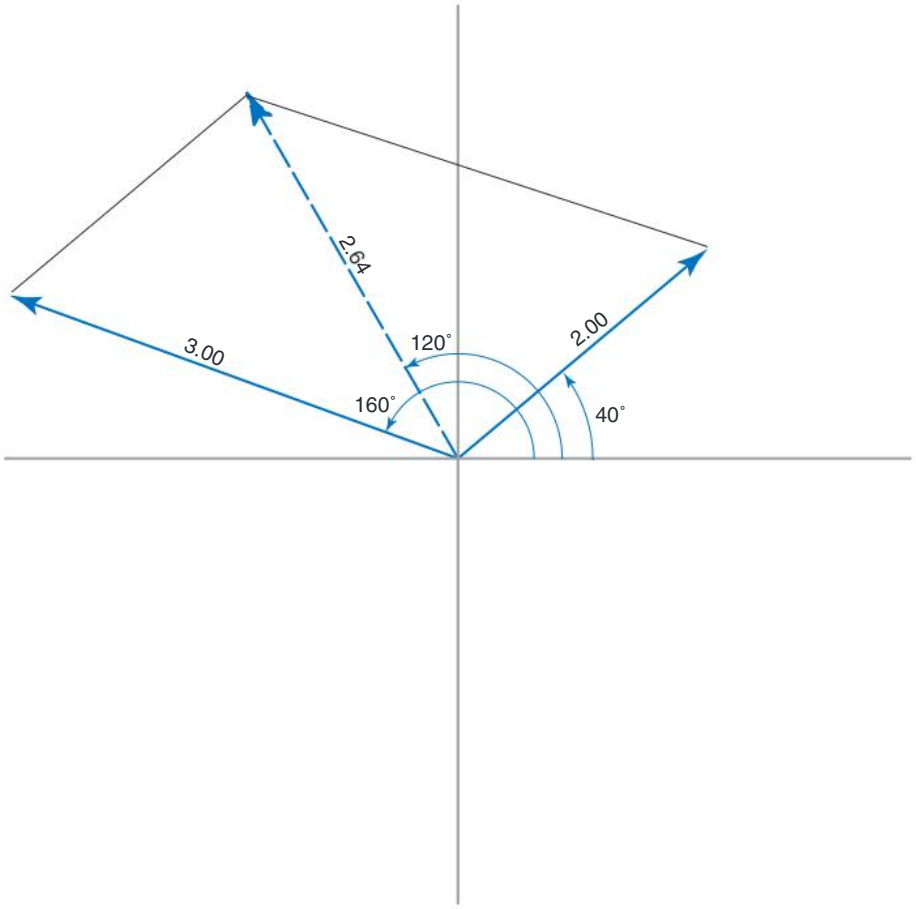


Figure 13.23 Graphically plotting two unequally powered obliquely crossed cylinders.
For −2.00 × 020, the axis is doubled and the power drawn at 40 degrees.
For −3.00 × 080, the axis is doubled and the power drawn at 160 degrees.
The resultant power is −2.64 along the 120-degree meridian.
The resultant axis is $\frac{120}{2}$ or 060 degrees.

The Formula Method

By using the graphical method, it is possible to develop a formula for finding the resultant of two obliquely crossed cylinders. This formula can be used to solve the problem or to construct a computer-based program to solve obliquely crossed cylinder problems. Without going into the derivation, the formula method is as follows:

1. If both cylinders are not in the same form, transpose one lens so that both are plus or both are minus.
2. Find the difference between the two cylinder axis angles. The angular difference in degrees between F_{cyl1} and F_{cyl2} will be called a. We will call the cylinder with the smaller axis value F_{cyl1} and the cylinder with the larger axis value, F_{cyl2}.
3. Find how far the new cylinder axis is from the cylinder with the smaller axis value (F_{cyl1}) by using the formula:

$$\tan 2\theta = \frac{F_{cyl2} \sin 2a}{F_{cyl1} + F_{cyl2} \cos 2a}$$

where:
F_{cyl1} = the power of the first cylinder
F_{cyl2} = the power of the second cylinder
a = the difference between the two cylinder axes in degrees, and
θ = how far the axis of the new cylinder is from the first cylinder axis

4. Find the axis of the new cylinder. This is done by adding θ to the axis of the first cylinder (the cylinder with the smaller axis).
5. Find the sphere power (S) resulting from the two cylinders crossing. This is done using the formula:

$$S = F_{cyl1} \sin^2\theta + F_{cyl2} \sin^2(a - \theta)$$

(Note: This is only the power of the new spherocylinder combination *if* the lenses being combined are *plano*-cylinders. If there are sphere components to the combining lenses, these will be added in later.)

6. Find the new cylinder power (C) using the formula:

$$C = F_{cyl1} + F_{cyl2} - 2S$$

7. Find the new total sphere power (S_{Total}) by adding the sphere powers in the original two lenses (S_1 and S_2) to the sphere power (S) resulting from the crossing of the cylinders.

$$S_{Total} = S + S_1 + S_2$$

Guiding Concepts for Anticipating the Sum of Two Obliquely Crossed Cylinder Lenses

In reality, few people will be using either the formula method or the graphical method to find the result of two obliquely crossed cylinders. Instead an online calculator will be used. However, it is useful to understand enough about lenses to know how two obliquely crossed cylinders or spherocylinders will interact. Box 13.3 gives the guiding concepts

BOX 13.3 Guiding Concepts for Obliquely Crossed Cylinders

Guiding Concepts	Example/Explanation
1. The sum of the spherical equivalents of two cylinder lenses will always be equal to the spherical equivalent of the resultant lens.	Here are two spherocylinder lenses. pl − 1.00 × 045 pl − 2.00 × 090 The spherical equivalent of the first lens is −0.50 D. The spherical equivalent of the second lens is −1.00 D. The sum of their spherical equivalents is −1.50 D. If the two spherocylinder lenses are combined, the resultant spherocylinder lens is −0.38 − 2.24 × 077. The spherical equivalent of the resultant spherocylinder lens is −1.50 D, which is the same as the sum of the spherical equivalents of these two plano-cylinder lenses.
2. If the axes of either two plus cylinder or two minus cylinder lenses are the same, then the resultant cylinder power will be the sum of the two cylinders.	When pl − 2.00 × 180 is combined with pl − 2.00 × 180, the result equals pl − 4.00 × 180.
3. When the axes of two cylinders are very close to one another, the resultant cylinder power closely approaches the sum of the two cylinders.	When pl − 2.00 × 002 is combined with pl − 2.00 × 178, the result equals −0.02 − 3.96 × 180.
4. If the axes of two equally powered cylinders are 90 degrees away from one another, the cylinder power will be zero and the sphere power resulting from the two combined cylinder components will change by the full power of the cylinder.	When pl − 2.00 × 090 is combined with pl − 2.00 × 180, the result is a −2.00 D sphere.
5. If the powers of two obliquely crossed cylinders are equal, the axis of the new cylinder will be halfway in between the axes of the two original cylinders.	When pl − 2.00 × 030 is combined with pl − 2.00 × 070, the result is −0.47 − 3.06 × 050. The axis 050 is halfway between 030 and 070.
6. If the cylinder powers of two obliquely crossed cylinders are unequal, the resulting cylinder axis will move in the direction of the axis of the stronger cylinder.	When pl − 2.00 × 030 is combined with pl − 1.00 × 070, the result is −0.31 − 2.39 × 042. (42 degrees is closer to 30 degrees than it is to 70 degrees.)
7. If the axes of two equally powered plano-cylinders are very close to being 90 degrees away from one another, A. the new cylinder power will drop to a very low power, B. the change in sphere power caused by the two combined cylinder components will be nearly equal to the power of the previous cylinder, C. the cylinder axis of the low-powered resultant cylinder will be halfway between the two axes of the original cylinders.	When pl − 2.00 × 088 is combined with pl − 2.00 × 002, the result equals −1.86 − 0.28 × 045.
8. If the axes of two *un*equally powered cylinders are 90 degrees away from one another, the new cylinder power will be the difference between the two cylinder powers, and the sphere power will increase by the amount of the smaller cylinder.	When pl − 2.00 × 090 is combined with pl − 1.00 × 180, the result equals −1.00 − 1.00 × 090.
9. If the axes of two *un*equally powered plano-cylinders are very close to being 90 degrees away from one another, A. the new cylinder power will be close to the difference between the previous two cylinder powers, B. the sphere power will increase by close to the amount of the smaller cylinder, C. the new axis will be close to the axis of the lens with the higher powered cylinder.	When pl − 2.00 × 088 is combined with pl − 1.00 × 002, the result equals −0.99 − 1.02 × 084.

used to help understand how two cylinder lenses will sum. Examples are included for two cylinders that are not at oblique angles with one another. Each question represents an important aspect in understanding how cylinders are added together. The answers shown here were obtained by exact calculations—not by estimations. However, to understand concepts, exact calculations are not important. The important thing to notice is the relative powers of the new cylinder and sphere and the approximate position of the new axis. Before reading further, proceed to Box 13.3 and become familiar with the guiding concepts shown there.

Conceptually Understanding Obliquely Crossed Spherocylinder Lenses

By using the guiding concepts for adding plano-cylinder lenses just presented in Box 13.3, apply these concepts to spherocylinders. Without doing full calculations, it is then possible to anticipate what new spherocylinder lens might result when adding two spherocylinder lenses together.

Although it is feasible to estimate the possible new combined spherocylinder lens, it is still difficult to come up with exact answers. Instead, let us look at this from the standpoint of how well we understand the concepts. Think about this from the viewpoint of a multiple-choice question. Using the concepts just learned, try to eliminate the impossible answers and arrive at the only feasible one.

Example 13.17

What is the sum of these two spherocylinder lenses? Their powers are:

$$+2.00 + 1.00 \times 070$$

and

$$+1.00 + 2.00 \times 050$$

Choose the correct response from these possible answers without either using the graphical method or doing a full mathematical calculation. (Answers are rounded.)

a. +3.00 + 2.37 × 064
b. +2.37 + 3.12 × 059
c. +2.50 + 2.75 × 058
d. +3.25 + 2.50 × 063
e. +3.12 + 2.87 × 057

Solution

We notice that the cylinder powers of the original lenses are not equal. According to concept 6 in Box 13.3, when cylinder powers are unequal, the resulting cylinder axis will be closer to the axis of the lens with the higher cylinder power. Halfway between the two axes is 060 degrees. This means the axis cannot be higher than 060 degrees. This immediately eliminates answers a and d.

We know that even if the cylinder axes were the same, the resulting cylinder power cannot be higher than the sum of the two cylinder powers (see concept 2). Even if the axes were equal, the highest possible cylinder power would be +3.00 D. This eliminates answer b.

According to concept 1, we know that the sum of the spherical equivalents of the two obliquely crossed spherocylinders will always equal the spherical equivalent of the resultant lens. The spherical equivalent of the +2.00 + 1.00 × 070 lens is +2.50, and the spherical equivalent of the +1.00 + 2.00 × 050 lens is +2.00. The sum of these two spherical equivalents is +4.50. We will look at answers c and e to see if either of these lenses have this same spherical equivalent.

For answer c, the spherical equivalent is +3.87, so this answer is incorrect. For answer e, the spherical equivalent is +4.50. Therefore, the correct answer is e.

LENS THICKNESS

Sagittal Depth

The formula that is the basis for determining lens thickness is the *sagittal depth*, or *sag formula*. This formula was introduced earlier in the chapter. Sagittal depth is the depth of the lens surface curve (see Figure 13.24). Remember that a chord is a straight line joining two points on the curve of a circle. In Figure 13.24, the two points on the curve are at the edges of the shaded lens, and the length of the chord equals the diameter of the lens.

To find the sagittal depth, it is necessary to know the length of the chord and the radius of curvature of the lens surface. Figure 13.25 shows the radius (r) as the hypotenuse of a right triangle. (Notice that this uses the same principles as were discussed for the lens clock previously in the chapter. Figure 13.25 is another view of what was shown in Figure 13.9.) The other two sides of the right triangle are y, which is one-half of the chord (or ½ the lens diameter), and $(r - s)$, which is the radius minus the sag. Because this triangle is a right triangle, the Pythagorean theorem can be used to help in finding the sagittal depth: (When discussing the lens clock, we used the Pythagorean theorem to find the radius of curvature [r].)

$$y^2 + (r - s)^2 = r^2$$

By transposition,

$$(r - s)^2 = r^2 - y^2$$

and

$$r - s = \sqrt{(r^2 - y^2)}$$

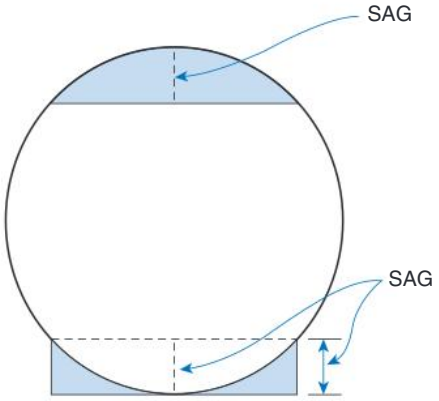


Figure 13.24 In this diagram, imagine the circle as representing a spherical glass ball. The *upper shaded area* in the diagram would show how a plus lens could be formed by slicing the top from the glass sphere. The thickness is labeled *SAG*, which is short for sagittal depth. If the slice is made farther down in the glass ball, both the size (lens diameter) and sagittal depth (thickness) of the shaded lens would be larger. (Remember, the slice through the circle is called the *chord*.) The *bottom shaded area* represents a minus lens. A knife-edged plus lens has the same center thickness that the edge of an infinitely thin minus lens would have when both diameters and curvatures are the same.

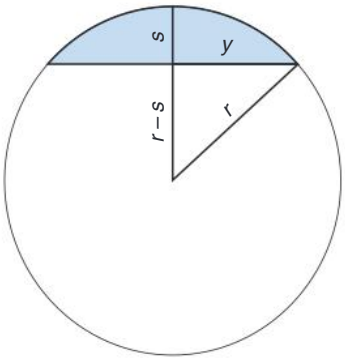


Figure 13.25 The geometry of the figure shows how the sag formula is derived from the Pythagorean theorem. Here, $y^2 + (r - s)^2 = r^2$.

Which simplifies to

$$-s = -r + \sqrt{(r^2 - y^2)}$$

And results in

$$s = r - \sqrt{(r^2 - y^2)}$$

This last equation is called the *accurate sag formula.*

The Approximate Sag Formula

Before the advent of hand calculators, simplified formulas yielding an approximate result were used to find the sagittal depth of a curved surface. To simplify calculations, the more complex formula of $s = r - \sqrt{(r^2 - y^2)}$ was simplified to the approximate sag formula:

$$s = \frac{y^2}{2r}$$

The *approximate sag formula* only works when the diameter is small and the radius of curvature is long. In other words, it only approximates well for small lenses with low-powered surfaces. Because it enjoyed such widespread usage, it is still seen and referred to. However, using the accurate sag formula is no longer as difficult and yields accurate results over the whole range of lens sizes and powers.

With that having been said, the approximate sag formula has made somewhat of a resurgence despite inherent limitations. This may be due to the ease of teaching and testing compared to the accurate sag formula. The learner does not become bogged down in working formulae and can give more attention to understanding how lens thickness works.

Here is an example problem using the approximate sage formula.

Example 13.18

A certain lens surface has a radius of curvature of 83.7 mm. The lens has a diameter of 50 mm. Using the approximate sag formula, find the sagittal depth of the front surface of the lens.

Solution

Using the approximate sag formula,

$$s = \frac{y^2}{2r}$$

$$s = \frac{(25)^2}{2(83.7)}$$

$$s = \frac{625}{167.4} = 3.7$$

The sagittal depth of the front surface equals 3.7 mm. Note that millimeters are used throughout this equation. Millimeters are used because that is the final unit measure we are interested in knowing. Any unit of measure may be used if it is used consistently.

Now we will consider the same problem again, this time using the accurate sag formula.

Example 13.19

Again, a lens surface has a radius of curvature of 83.7 mm. The lens has a diameter of 50 mm. This time use the accurate sag formula to find the sagittal depth of the front surface of the lens.

Solution

Using the accurate sag formula,

$$s = r - \sqrt{(r^2 - y^2)}$$

The value for r has been given as 83.7 mm. The *value of* y is half of the lens diameter. Since the lens has a diameter of 50 mm, y is 25 mm. Therefore,

$$s = 83.7 - \sqrt{(83.7)^2 - (25)^2}$$
$$= 83.7 - 79.9$$
$$= 3.8\,\text{mm}$$

Again, the s, r, and y can be expressed in meters or millimeters as long as all are in the same units. In this case, as before, all three are expressed in millimeters. This time the sagittal depth of the surface is found to be 3.8 mm. Both the approximate and accurate sag formulas give almost the same result. This should not be much of a surprise. If this lens is made from 1.523 index glass, the power of the surface is +6.25 D. (We determine this by using the Lensmaker's formula to find lens surface power.) The power is relatively low (since the radius of curvature is relatively long), and the chord diameter (50 mm) is not that large. Thus, the approximate sag formula approximates the sagittal depth well.

Example 13.20

Suppose a lens has a true base curve (TBC) of +7.19 D. If the diameter of the lens is 52 mm, what is the sagittal depth of the front surface at the full 52-mm diameter? (Use the accurate sag formula to find the sagittal depth.)

Solution

To find the sagittal depth of the surface, we need to know r and y. The y value is easy to find, since it is half of the 52-mm (chord) diameter. In other words, $y = 26$ mm. However, to find the radius, we must first use the *Lensmaker's formula*:

$$r = \frac{n - 1}{F}$$

True base curve (TBC) is based on a lens clock value, and the lens clock uses an assumed index of refraction of 1.53. Therefore,

$$r = \frac{1.53 - 1}{F}$$

To find r for a +7.19 D true base curve surface, we use:

$$r = \frac{1.53 - 1}{+7.19}$$
$$= \frac{0.53}{+7.19}$$
$$= 0.0737\,\text{m}$$

The sag formula requires that all the terms in the equation be expressed in the same units. Converting 0.0737 m to millimeters makes $r = 73.7$ mm. Now we can use the sag formula:

$$s = r - \sqrt{(r^2 - y^2)}$$
$$= 73.7 - \sqrt{(73.7)^2 - (26)^2}$$
$$= 73.7 - \sqrt{5431.7 - 676}$$
$$= 73.7 - \sqrt{4755.7}$$
$$= 73.7 - 69.0$$
$$= 4.7\,\text{mm}$$

The sagittal depth of a +7.19 D true base curve surface on a 52-mm lens is 4.7 mm.

(Using the approximate sag formula, the sagittal depth is equal to 4.6 mm.)

Example 13.21

A lens has a true base curve (TBC) of +7.19, a diameter of 52 mm, a plano back surface, and an edge thickness (ET) of 1.6 mm. What is the center thickness (CT) of the lens?

Solution

We have already calculated the sagittal depth of the front surface of this lens in Example 13.20. To visualize what this plano-convex lens looks like, see Figure 13.26, *A*. From the figure we can see that the CT of the lens will be equal to the sagittal depth of the front surface (s_1) plus the edge thickness (ET). Therefore, the CT of this lens is:

$$\text{CT} = s_1 + \text{ET}$$
$$\text{CT} = 4.7\,\text{mm} + 1.6\,\text{mm}$$
$$= 6.3\,\text{mm}$$

In Figure 13.26 the ET has been drawn exceptionally thick to keep front- and back-surface sagittal depth labels (s_1 and s_2) from overlapping. If drawn to scale, the edge would be much thinner and would correspond more accurately to the example.

Thickness of Meniscus Lenses

Although a few ophthalmic lenses worn today may be plano-concave or plano-convex, most lenses have a convex front surface and a concave back surface. These lenses are referred to as *meniscus lenses*. To determine the thickness of a meniscus lens, calculations must be made for both the front and back surfaces.

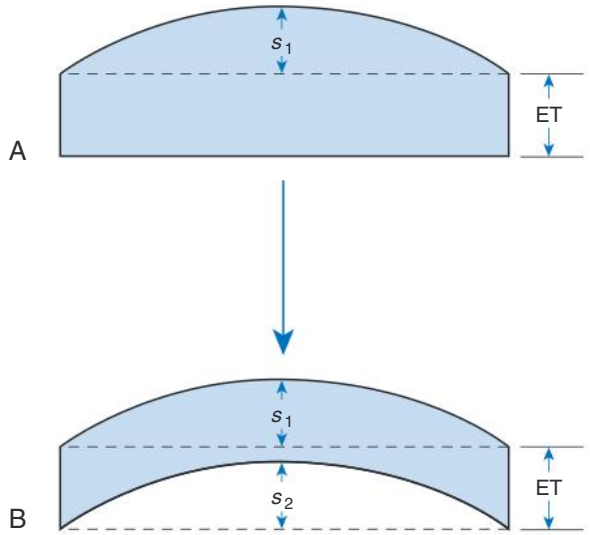


Figure 13.26 **A**, For a plus lens with a convex front surface and plano (flat) back surface, lens center thickness is equal to the edge thickness (ET) plus the sagittal depth of the front surface (s_1). **B**, A meniscus lens has a convex front surface and a concave back surface. The center thickness of a meniscus lens is equal to the ET plus the sagittal depth of the front surface (s_1) minus the sagittal depth of the second surface (s_2).

To better understand the construction of such a lens and how calculations are carried out, think of the meniscus lens as being two lenses glued together. A meniscus lens can first be thought of as a plano-convex lens as shown in Figure 13.26, *A*. For a plano-convex lens, center thickness (CT) is equal to the sagittal depth of the first surface (s_1) plus the edge thickness (ET), or:

$$\text{CT} = s_1 + \text{ET}$$

After CT calculations have been carried out for a plano-convex lens, imagine grinding a minus curve on the back of the lens as shown in Figure 13.26, *B*. This reduces the CT by the sagittal depth of this freshly ground concave surface. The CT then becomes:

$$\text{CT} = s_1 + \text{ET} - s_2$$

or

$$\text{CT} = s_1 - s_2 + \text{ET}$$

where s_2 is the sagittal depth of the second surface.

Although sagittal depths may be found using either the accurate sag formula or the approximate sag formula, for better results, the accurate sag formula is more appropriate.

Concepts in Understanding Lens Thickness

In ophthalmic dispensing, one of the primary motivations for understanding lens thickness concepts is that it is easier to visualize and understand how each prescription will look in different types of frames. In fact, knowing thickness concepts will keep one from ordering a lens prescription for a frame that will result in something unsightly or even unsuitable. In going through the next section, here is a quick review of the formulas needed for working the problems in the sequence in which they will normally be used.

$$y = \frac{\text{Chord diameter}}{2}$$

$$r = \frac{n-1}{F}$$

$$s = r - \sqrt{(r^2 - y^2)} \text{ or } s = \frac{y^2}{2r}$$

$$CT = s_1 - s_2 + ET$$

As we progress through this section, some of the examples may seem overly simplistic. This is done intentionally to make certain that each conceptual step is understood.

Center Thickness for a Plano-Convex Lens

Example 13.22

What is the center thickness (CT) for a lens with the following dimensions?

Lens power = +3.00 D
Index of refraction = 1.53
Lens diameter = 50 mm

Lens form is plano-convex (+3.00 D front curve and a plano back surface).

Edge thickness (ET) is zero. (A lens with a zero ET is said to be knife-edged.)

The lens has no decentration. (The optical center [OC] is exactly in the middle of the edged shape.)

Solution

In learning to conceptualize lens thickness, it is helpful to try to draw a picture of the lens. In this case, because the lens is round and the OC is in the middle of the lens, the chord diameter is the same as the eyesize or the A dimension of the frame.

This information will allow us to draw a cross section of the lens as shown in Figure 13.27. The semidiameter (y) is equal to:

$$y = \frac{\text{Chord diameter}}{2}$$

$$= \frac{50}{2}$$

$$= 25\,\text{mm}$$

The radius of curvature of the front surface is found using the Lensmaker's formula:

$$r = \frac{n-1}{F}$$

$$= \frac{1.53-1}{3.00}$$

$$= \frac{0.53}{3}$$

$$= 0.1766\,\text{m or } 176.7\,\text{mm}$$

If we use the accurate sag formula, the sagittal depth of the lens surface is:

$$s_1 = r - \sqrt{r^2 - y^2}$$

$$= 176.7 - \sqrt{(176.7)^2 - (25)^2}$$

$$= 176.7 - \sqrt{31{,}223 - 625}$$

$$= 176.7 - \sqrt{30{,}598}$$

$$= 176.7 - 174.9$$

$$= 1.8\,\text{mm}$$

(Using the approximate sag formula and rounding to the nearest tenth millimeter also results in $s_1 = 1.8$ mm.)

We can use the formula for CT. But even before using the formula, we know that the CT will be 1.8 mm. This is because there is no ET and the back of the lens is flat. Because the lens is flat, the sagittal depth of the second surface (s_2) is equal to zero. Here is the formula solution:

$$CT = s_1 + s_2 + ET$$
$$= 1.8 - 0 + 0$$
$$= 1.8\,\text{mm}$$

Before finishing the problem, we need to look at the whole lens—center, left edge, right edge, and top and bottom edges. To look at the lens in horizontal and vertical cross sections, see Figure 13.28.

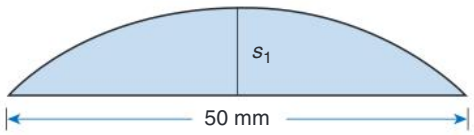


Figure 13.27 The center thickness of a plano-convex lens with a zero edge thickness is equal to the sagittal depth of the convex surface.

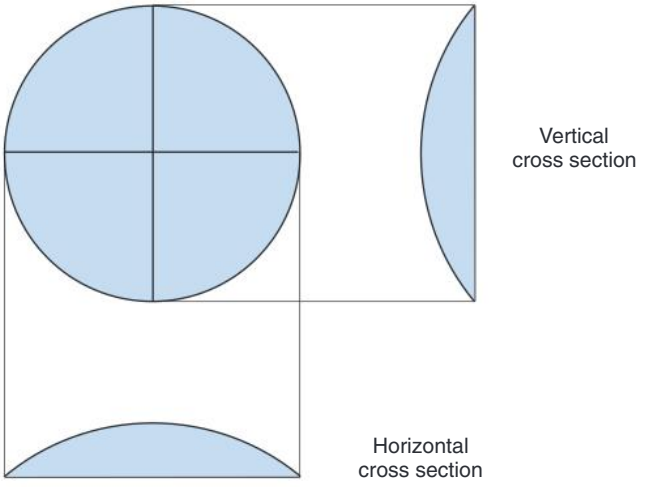


Figure 13.28 Horizontal and vertical cross sections of a knife-edged plano-convex lens.

Example 13.23

A lens is a +3.00 D sphere with the same dimensions as the previous lens, except that this lens is ground so that the resulting edge is 1.0 mm thick. What is the center thickness (CT) of the lens?

Solution

The answer here is intuitive. If the previous lens has an edge thickness (ET) of zero and is 1.8 mm thick in the center, then this lens with a 1.0 -mm ET will be 1.0 mm thicker everywhere, resulting in a lens of 2.8 mm CT. But the example was introduced to further progressive reasoning in finding lens thickness.

The lens is drawn as shown in Figure 13.29. We find s_1, the sagittal depth of the first surface, exactly as before. The figure shows us (and the formula tells us) that:

$$CT = s_1 - s_2 + ET$$

However, since the sagittal depth of the second surface is zero, it does not factor in. So in this case,

$$CT = (\text{The sagittal depth of the front surface}) + (ET)$$

Therefore, for this lens,

$$CT = 1.8\text{mm} + 1.0\text{mm}$$
$$= 2.8\text{mm}$$

(Note: When drawing lens cross sectional figures like the one shown in Figure 13.29, remember that the CT in both horizontal and vertical cross sections must always be the same. A lens only has one center thickness.)

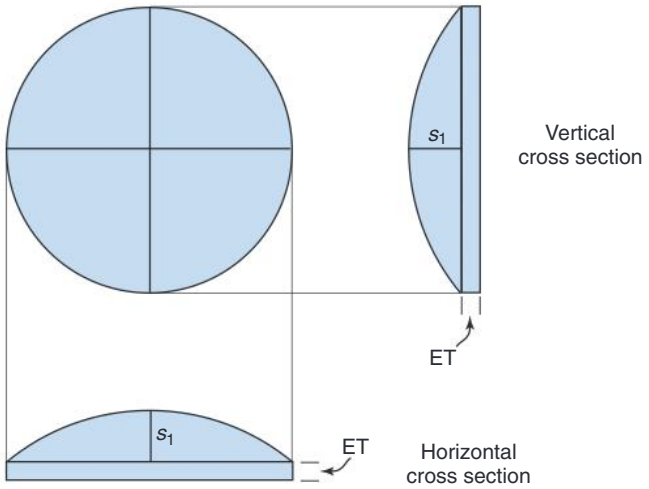


Figure 13.29 When a plano-convex lens (with no decentration) has edge thickness (ET), the center thickness of the lens equals the sagittal depth of the convex surface plus the ET.

Example 13.24

A cylinder lens has a power of pl + 3.00 × 090. It is edged to a 50-mm round shape and has no decentration. The thinnest edge of the lens is zero. In other words, at its thinnest point, the lens is "knife edged." This lens has a plano back surface, and the index of refraction is 1.53.

A. What is its center thickness (CT)?
B. Where are the thin knife edges located?
C. How thick are the thickest edges?

Solution

A. If this lens is drawn as shown in Figure 13.30. We see the axis meridian at 90 degrees and the power meridian at 180 degrees. The lens has the same +3.00 D power and 50-mm chord size as the +3.00 D sphere in the previous example. Therefore, since it is knife edged and plano-convex in form, the sagittal depth of the front surface is the same 1.8 mm that we found in the previous example. This equals the CT of the lens.
B. The knife edges are on the left and right sides of the lens in the 180-degree (horizontal) power meridian. This is shown in Figure 13.30.
C. Because the lens is plano in the 90-degree axis meridian, the thickness remains the same all along the axis. If this plano-cylinder lens is 1.8 mm thick in the center, it must also be 1.8 mm thick at the top and bottom edges.

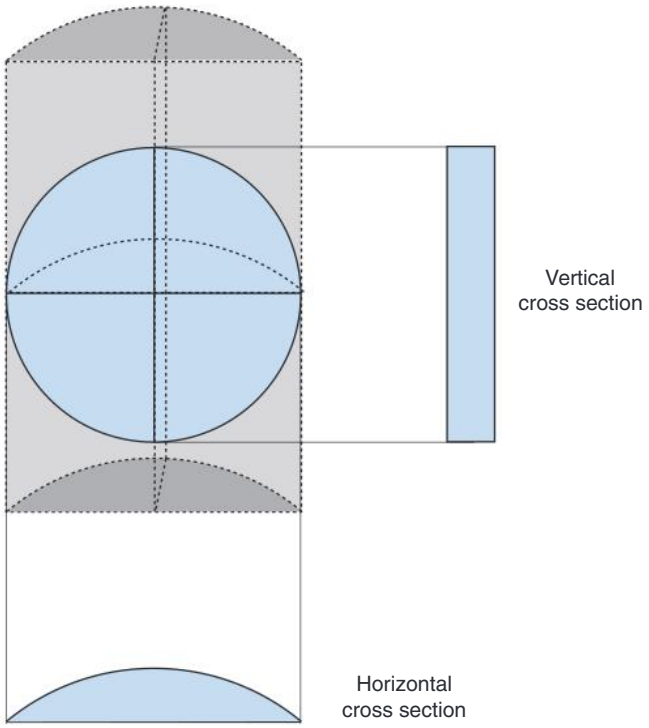


Figure 13.30 Cross sections of a plano-convex cylinder lens in the major meridians of the lens. When the plano-convex cylinder (shown with axis at 90 degrees) is edged to a round shape, the horizontal cross section in the power meridian looks like a normal plus lens. The center is thick, and the edges on either side are thin. In the vertical (axis) meridian, because the power is zero, the thickness of the lens is the same at the center and the top and bottom edges.

Edge Thickness for a Plano-Concave Lens

The methodology used for finding edge thickness of minus lenses is practically the same as that used to find the center thickness for plus lenses.

Example 13.25

A minus sphere lens has been edged to a 50-mm round shape. The optical center (OC) is exactly at the center of the edged shape. The front surface of the lens is flat ($F_1 = 0$), and the back-surface curve has a power of −3.00 D ($F_2 = -3.00$ D). The refractive index is 1.53. If this minus lens has a center thickness (CT) of zero (the center is infinitely thin), what is the edge thickness (ET)?

Solution

Set the problem up with a drawing. That drawing is shown in Figure 13.31. Here, we see the round lens with horizontal and vertical cross sections. Because the lens is spherical and round with the OC in the middle of the lens shape, both horizontal and vertical cross sections of the drawing are identical. Since the lens has zero center thickness and the front of the lens is flat, the sagittal depth of the back surface will equal the edge thickness of the lens.

The sagittal depth of the back surface is found in the same manner as was done for the front surface sagittal depth for the plus lens. The same dimensions have been chosen as in earlier examples, conveniently allowing us to know that $s_2 = 1.8$ mm.

If we were to use the formula to find edge thickness, we would use:

$$CT = s_1 - s_2 + ET$$

This transposes to be:

$$\begin{aligned} ET &= CT - s_1 + s_2 \\ &= 0 - 0 + 1.8 \\ &= 1.8\text{mm} \end{aligned}$$

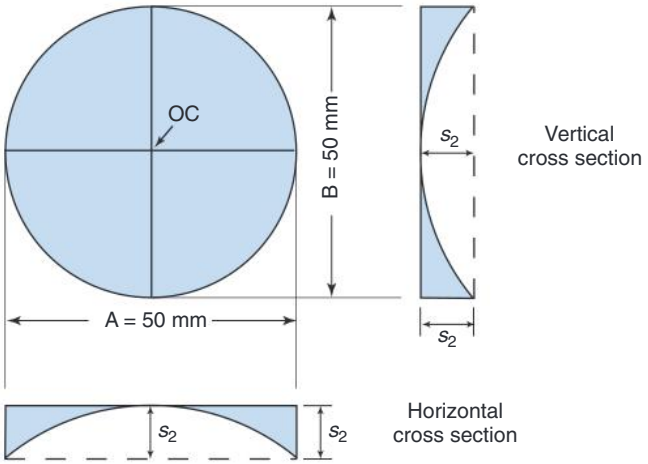


Figure 13.31 Horizontal and vertical cross sections of a plano-concave lens with an infinitely thin center. With zero center thickness, the edge thickness equals the sagittal depth of the concave (minus) surface. *OC,* optical center.

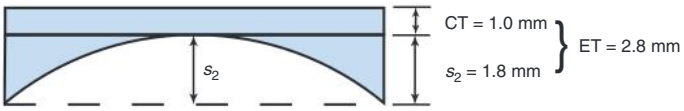


Figure 13.32 The edge thickness (ET) of a plano-concave (minus) lens is the sum of the center thickness (CT) and the sagittal depth of the concave surface.

Example 13.26

A lens is a −3.00 D lens with the same dimensions as the previous lens except for center thickness (CT). This lens has a 1.0-mm CT. How thick are the lens edges in the horizontal and vertical meridians?

Solution

As the center increases in thickness, so do the edges. So if the sagittal depth of the second surface is 1.8 mm, and the center thickness is 1.0 mm, then the edge thickness will be 2.8 mm (Figure 13.32). This should be intuitive. However, the formula sequence is:

$$\begin{aligned} ET &= CT - s_1 + s_2 \\ &= 1.0 - 0 + 1.8 \\ &= 2.8\text{mm} \end{aligned}$$

The object of these examples is to intuitively know how center and edge thickness work, not to work a formula. It is highly unlikely that someone will sit down in an optical dispensary and calculate center or edge thickness. However, it is very important to conceptually know what an ophthalmic lens prescription will look like in a given frame shape and lens material before it is ever ordered.

Example 13.27

A lens has the following parameters:

- Power = pl − 3.00 × 090
- Lens form: a plano-concave cylinder
- The lens is edged 50 mm round.
- The optics of the lens are centered in the edged shape (i.e.,? there is no decentration).
- Index of refraction is 1.53.
- The center thickness (CT) of the lens is 1.0 mm.

What are the edge thicknesses (ETs) in the horizontal and vertical meridians?

Solution

Begin by setting up the problem as a drawing. Figure 13.33 shows a plano minus cylinder oriented at axis 90 degrees. Now imagine edging that cylinder to a 50-mm round shape by drawing a circle over it. (The flat-plane drawing of the circle will not exactly mesh with the three-dimensional aspects of the plano-cylinder drawing but should still be understandable.)

Now draw horizontal and vertical cross sections of the lens. A plano minus cylinder lens has the same thickness along its axis meridian. Therefore, the top and bottom edges of the lens have the same thickness as the center of the lens (1.0 mm).

The plano minus cylinder lens thickens toward the edge in the power meridian. Edge thickness along the power meridian is equal to the center thickness plus the sagittal depth of the second surface in the meridian. In this case, as before, the

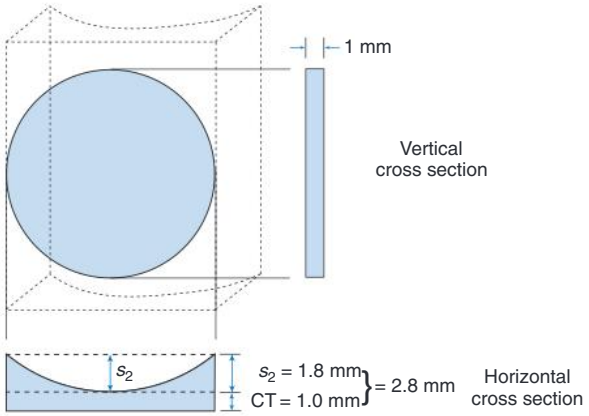


Figure 13.33 Horizontal and vertical cross sections of a plano-concave cylinder with center thickness (CT). The thickness along the cylinder axis does not change.

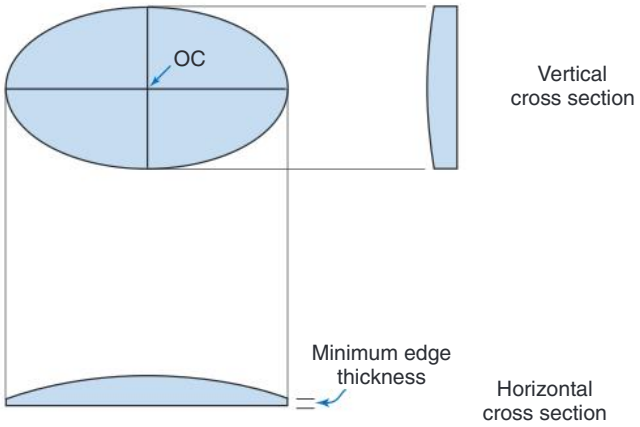


Figure 13.34 When a plus sphere lens is edged to an oval shape, edge thickness will be greatest for the edge closest to the optical center (OC) of the lens.

sagittal depth is 1.8 mm. So the edge thicknesses on both sides of the 180-degree meridian are 2.8 mm. As before:

$$\begin{aligned} ET_{180} &= CT - s_1 + s_2 \\ &= 1.0 - 0 + 1.8 \\ &= 2.8\text{mm} \end{aligned}$$

Center and Edge Thicknesses for Meniscus Lenses

Here are some example problems for plus and minus meniscus lenses using the same principles that have already been covered up to this point.

Example 13.28

What is the center thickness (CT) for this +2.00 D lens that is edged to a horizontally oval shape with no decentration? The lens parameters needed to solve the problem are:

- $F_1 = +8.00$ D (front-surface power)
- $F_2 = -6.00$ D (back-surface power)
- $n = 1.53$
- Minimum edge thickness (ET) =1.5 mm
- A = 50 mm (This is the horizontal dimension of the oval shape.)
- B = 30 mm (This is the vertical dimension of the oval shape.)
- The optical center (OC) of the lens is in the center of the lens shape.

Solution

Before we start any calculations, we need to know where the thinnest edge(s) of the lens are found. The easiest way to find the location of the thinnest edge(s) is to conceptualize the lens. To do this, ignore the fact that the lens is a meniscus lens. Imagine it as a plano-convex lens of power +2.00 D. If we draw it out this way, it would appear as shown in Figure 13.34. We know that a plus lens is thickest in the middle and thins gradually as the distance from the center increases. Therefore, *the thinnest edge of a plus sphere lens will be the edge farthest from the lens OC.*

Both left and right edges are equally far from the OC and are the points that are farthest from the OC. The top and bottom edges are closer to the OC and are thicker.

Knowing this, we can redraw the horizontal cross section as it really is. This is shown in Figure 13.35. If we can find the sagittal depths for the first and second surfaces, we will know what the center thickness is.

For the first surface:

$$\begin{aligned} r &= \frac{n-1}{F_1} = \frac{1.53-1}{8.00} \\ &= 0.06625\text{m} = 66.25\text{mm} \\ s_1 &= r - \sqrt{(r)^2 - (y)^2} \\ &= 66.25 - \sqrt{(66.25)^2 - (25)^2} \\ &= 66.25 - \sqrt{4389 - 625} \\ &= 66.25 - 61.35 \\ &= 4.9\text{mm} \end{aligned}$$

For the second surface:

$$\begin{aligned} r &= \frac{1-n}{F_2} = \frac{1-1.53}{-6} \\ &= 0.08833\text{m} = 88.33\text{mm} \\ s_2 &= r - \sqrt{(r)^2 - (y)^2} \\ &= 88.33 - \sqrt{(88.33)^2 - (25)^2} \\ &= 88.33 - \sqrt{7803 - 625} \\ &= 88.33 - 84.72 \\ &= 3.6\text{mm} \end{aligned}$$

Therefore, the center thickness of this lens is:

$$\begin{aligned} CT &= s_1 - s_2 + ET \\ &= 4.9 - 3.6 + 1.5 \\ &= 2.8\text{mm} \end{aligned}$$

If we were to use the approximate sag formula to calculate sagittal depths, s_1 would equal 4.7 instead of 4.9 and s_2 would equal 3.5 instead of 3.6. Because the power of the first surface is higher, the error will be higher. Since the lens diameter and power is not that large overall, the final answer still comes out to be very close to what was found using the accurate sag formula. The CT found using the approximate sag formula will be:

$$\begin{aligned} CT &= s_1 - s_2 + ET \\ &= 4.7 - 3.5 + 1.5 \\ &= 2.7\text{mm} \end{aligned}$$

This is very close to the CT of 2.8 mm found using the accurate sag formula.

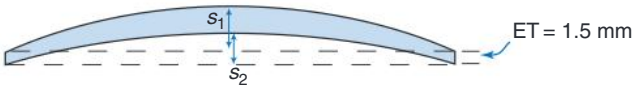


Figure 13.35 The center thickness (CT) of a meniscus lens is equal to the sagittal depth of the first surface (s_1) minus the sagittal depth of the second surface (s_2) plus the edge thickness (ET) (CT = $s_1 - s_2$ + ET).

Example 13.29

A −2.00 D lens has the following parameters:

- $F_1 = +6.00$ D
- $F_2 = -8.00$ D
- $n = 1.53$
- Center thickness (CT) = 1.5 mm
- It is edged to a horizontal oval shape in which
  - A = 50 mm (horizontal dimension)
  - B = 30 mm (vertical dimension)

How thick are the lens edges in both the horizontal and the vertical meridians?

Solution

Notice first that the minus lens in this example and the plus lens in the previous example have much in common. Even their surface curves are the same except that now the 6-D curve is on the front and the 8-D curve on the back. Remember that a minus lens is thinnest in the center and gradually increases in thickness toward the edges. The edge closest to the center is thinnest; the farthest edge thickest. To solve the problem, begin by drawing it out. This is shown completed in Figure 13.36.

For the horizontal meridian:

To find the edge thickness (ET) of the horizontal meridian, we know the chord diameter is 50 mm. The index and surface curves are the same as in the previous problem. Therefore, for the +6.00 front curve, the sagittal depth (s_1) is 3.6 mm. The second surface of −8.00 has a sagittal depth (s_2) of 4.9 mm. This gives an edge thickness of:

$$\begin{aligned} ET &= CT - s_1 + s_2 \\ &= 1.5 - 3.6 + 4.9 \\ &= 2.8\,mm \end{aligned}$$

For the vertical meridian:

Even though the curves in the vertical meridian are the same as the horizontal meridian, the sagittal depths will be different because the chord diameter (or chord length) is smaller. For the +6.00 D surface, we already know that the surface radius is 88.33 mm. The semidiameter of the vertical chord diameter is:

$$\begin{aligned} y &= \frac{\text{Chord diameter (or length)}}{2} \\ &= \frac{30\,mm}{2} \\ &= 15\,mm \end{aligned}$$

So sagittal depth for the first surface in the 90-degree meridian is:

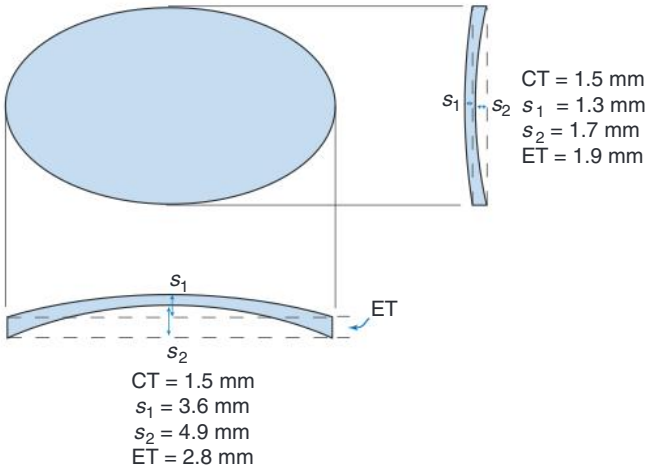


Figure 13.36 Horizontal and vertical cross sections of a minus sphere meniscus lens that has been edged oval. *CT*, center thickness; *ET*, edge thickness.

$$\begin{aligned} s_1 &= r - \sqrt{r^2 - y^2} \\ &= 88.33 - \sqrt{(88.33)^2 - (15)^2} \\ &= 88.33 - \sqrt{7803 - 225} \\ &= 88.33 - 87.05 \\ &= 1.3\,mm \end{aligned}$$

The sagittal depth for the second surface in the 90-degree meridian is:

$$\begin{aligned} s_2 &= r - \sqrt{r^2 - y^2} \\ &= 66.25 - \sqrt{(66.25)^2 - (15)^2} \\ &= 66.25 - \sqrt{4389 - 225} \\ &= 66.25 - 64.53 \\ &= 1.7\,mm \end{aligned}$$

This makes the top and bottom edge thickness equal to:

$$\begin{aligned} ET &= CT - s_1 + s_2 \\ &= 1.5 - 1.3 + 1.7 \\ &= 1.9\,mm \end{aligned}$$

So using the accurate sag formula, the left and right horizontal edge thicknesses of this lens are 2.8 mm and the top and bottom vertical edge thicknesses are 1.9 mm.

If we were to have used the approximate sag formula, the horizontal ETs would be 2.7 mm. The vertical ETs would be 1.9 mm, which is the same value as was found using the accurate sag formula. This should be no surprise because of the small chord diameter of the vertical meridian.

Determining Lens Diameter for Noncentered Lenses

The lens diameter needed to find the correct sagittal depth value depends on both the frame size and the location of the OC. For most prescription eyewear, once the lens has been edged, the OC is not in the middle of the lens. To visualize the situation, mark the point on an

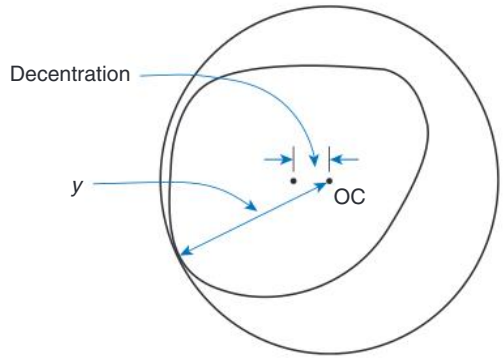


Figure 13.37 The diameter used in calculating lens thickness is basically the same as that used for minimum blank size. The only difference is that the 2-mm chipping factor is ignored. *OC,* optical center.

edged lens where the OC will fall. Next, draw a line from the OC to the point on the lens edge that is farthest from the OC (Figure 13.37). The resulting line is the *y* value we are interested in. Twice *y* is very close to the *minimum blank size* (see Chapter 5). In fact, when considering single-vision uncut lenses, the diameter we are interested in is equal to the minimum blank size (MBS) without an extra 2-mm safety factor for lens chipping that is normally included in the MBS formula. The formula for this diameter, which we will call the *chord diameter,* is:

$$\text{Chord diameter} = \text{ED} + (\text{A} + \text{DBL} - \text{Far PD})$$

where

ED = the effective diameter of a lens
A = the boxing eye size
DBL = the distance between lenses
Far PD = the wearer's interpupillary distance for distance viewing

This chord diameter formula may be used for both single-vision and multifocal lenses.

Estimating Edge Thickness

It can be very useful to be able to estimate edge thickness quickly. Such estimates are useful when asked, "How thick will my lenses be?" It is not possible to accurately know edge or center thicknesses without calculating chord diameter and sagittal depth values. To make estimations easier, calculations can be dropped by assuming equal decentration for all cases and by using the ED of the frame instead of chord diameter. This means that for a lens having an ED of 50 mm, we can use a constant (*K*) of 0.7 and multiply it by the absolute power value of the lens. (No plus or minus signs are required.) The constant used for lenses with an ED of 50 mm is 0.7. Lenses with a 58-mm ED call for a constant of 1.0. If the numbers (50, 0.7) and (58, 1.0) can be remembered, constants other than 0.7 and 1.0 can be estimated, depending on how close the ED of the frame is to 50 or 58. (These estimations are for low-index glass or plastic lenses. To estimate thickness for higher index materials, it is feasible to reduce the constants of 0.7 and 1.0 to somewhat smaller values. The higher the index of refraction is, the lower the value of the constant will be.)

Example 13.30

Estimate the edge thickness (ET) of a −6.00 D lens that has a center thickness (CT) of 2.2 mm and is to be placed in a frame with an effective diameter (ED) of 55 mm.

Solution

A 55-mm ED is more than halfway between 50 and 58. This means that the constant chosen will be more than halfway between 0.7 and 1.0. Halfway is 0.85, but we want to round to the nearest tenth so we can multiply it easily without using a calculator. The constant chosen will be 0.9. Edge thickness is:

$$\begin{aligned}\text{Edge thickness} &= K(F) + \text{Center thickness}\\ &= 0.9\,(6.00) + 2.2\\ &= 5.4 + 2.2\\ &= 7.6\,\text{mm}\end{aligned}$$

The lens has an estimated edge thickness of 7.6 mm.

(Note: The same type of formula also works to estimate the center thickness of a plus lens. Just exchange center and edge thickness so that it reads:

$$\text{Center thickness} = K(F) + \text{Edge thickness}$$

Enter the expected minimum edge thickness for the plus lens and find the expected center thickness.

Estimating Thickness When Prescribed Prism Is Present

When a lens has prism as part of the prescription, for estimation purposes, one-half of the prescribed prism amount is added to lens thickness. (The reason why prism changes the thickness of a lens will be explained more fully in the chapter on prism.)

Including prism, the rule of thumb for estimating lens thickness can be expressed as:

$$\text{CT or ET} = K(F) + (\text{ET or CT}) + P/2$$

where

K = the constant
F = the power of the lens
P = the power of the prism

For minus lenses, ET is to the left of the equal sign and CT is to the right. The reverse is used for plus lenses.

This method is intended to provide only a rough estimation of edge or center thickness and cannot be unerringly depended upon. When prism is included, this method estimates the worst case (thickest) result. In practice, the base direction of the prism will influence final center or edge thickness. (For how base direction influences overall prism thickness, see Chapter 16 in the section *How Prescribed Prism Affects Lens Thickness.*)

Example 13.31

Estimate the edge thickness (ET) of the lens in Example 13.30 if it contains 3 Δ of base-out prism.

Solution

The thickness factor for prism is an estimated 0.5 mm for every diopter of prism. This increases the estimated thickness by 1.5 mm. Therefore, the estimated edge thickness is:

$$\begin{aligned}\text{ET} &= K(F) + \text{CT} + \frac{P}{2}\\ &= 0.9(6.00) + 2.2 + 1.5\\ &= 9.1\,\text{mm}\end{aligned}$$

Example 13.32

A person with right and left lens powers of +5.00 D is wanting to choose a frame with an effective diameter (ED) of 58 mm while using standard CR-39 plastic lens material. There is no prescribed prism present. If the edge were to be 2.0 mm, how thick would you estimate the center will be? Use the rule of thumb to find your answer.

Solution

The constant (K) for a 58-mm ED is 1.0 mm. We use the same rule of thumb, but we substitute center thickness for edge thickness and edge thickness for center thickness.

$$\text{Center thickness} = K(F) + \text{ET} + \frac{P}{2}$$

We have no prism, and the edge thickness is 2.0 mm. A 58-mm ED results in a constant (K) of 1.0. So center thickness will be:

$$\text{Center thickness} = 1(5) + 2.0 + 0 = 7\,\text{mm}$$

A thickness of 7 mm is going to be a big disappointment and, if not rejected outright, is likely to result in wearer dissatisfaction.

CURVATURE IN AN OBLIQUE MERIDIAN

When specifying lens curvature, the curve can be denoted by either its radius of curvature (r) or by the unit called *Curvature*.

A spherically curved surface has a specific *radius* of curvature (r). The *Curvature* of a surface, specified with R, is the inverse of the radius of curvature in meters, or reciprocal meters (m^{-1}). In other words,

$$R = \frac{1}{r}$$

A plano plus cylinder appears as shown in Figure 13.38. In the figure there is no curve to the lens surface in the axis meridian. The surface is flat. In the power meridian, the surface has maximum curvature. Therefore, there is zero curvature along the axis of the plano-cylinder lens surface. Along the power meridian, the curvature is R. In between the axis meridian and the power meridian, curvature will increase by degree (Figure 13.39). The specific curvature of the surface may be found using the equation:

$$R_\theta = R_{\text{cyl}} \sin^2\theta$$

where
R_θ = Curvature in the oblique meridian
R_{cyl} = Curvature in the power meridian
and

θ = The angle between the oblique meridian and the cylinder axis.

The short-cut method says that since, for a lens surface in air,

$$F = \frac{n-1}{r}$$

or

$$F = (n-1)R$$

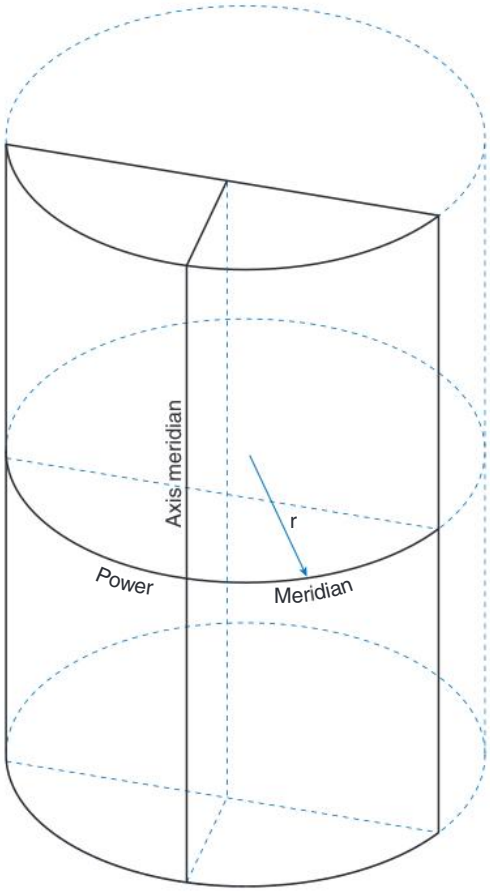


Figure 13.38 A plano plus cylinder has no power in the axis meridian. The refractive power in the power meridian depends on the index of refraction of the material and the radius of curvature.

then

$$R = \frac{F}{n-1}$$

It would seem logical, then, that if

$$R_\theta = R_{\text{cyl}} \sin^2\theta$$

then we should be able to say that

$$\frac{F_\theta}{n-1} = \frac{F_{\text{cyl}}}{n-1} \sin^2\theta$$

and

$$F_\theta = F_{\text{cyl}} \sin^2\theta$$

Unfortunately this assumption is not entirely correct. Although the curvature of a cross section changes, and "power" in an oblique cylinder meridian may be read using a lens clock on the surface, technically a plano-cylinder does not vary in power along an oblique meridian. It only varies in curvature. However, this sine-squared approximation method can be helpful in certain circumstances.

Using Sine-Squared θ to Find the "Power" of the Cylinder in an Oblique Meridian

To use the sine-squared approximation method for finding the "power" of a cylinder in an oblique meridian, use the following steps:

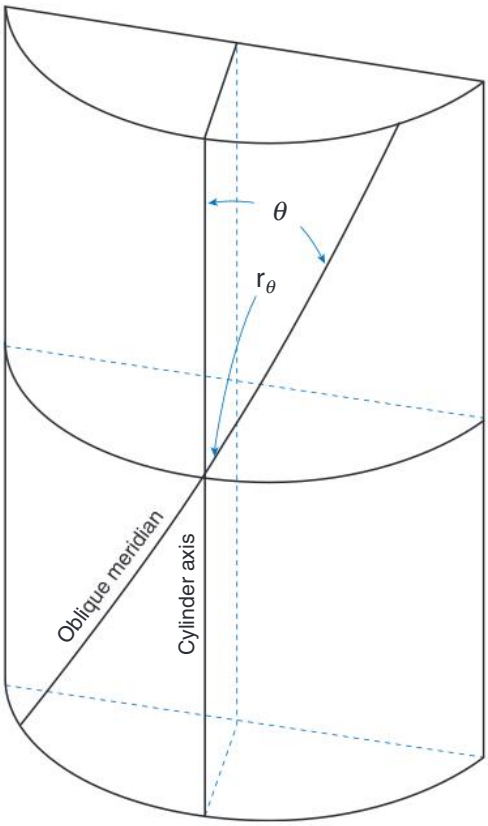


Figure 13.39 The radius of curvature, r_θ, in an oblique meridian of a plano plus cylinder lens will vary depending on the power of the cylinder curve and the angle (θ) of the oblique meridian.

1. Find theta.
   Theta (θ) is the difference between the meridian in question and the axis of the cylinder.
2. Apply the sine-squared approximation formula ($F_\theta = F_{cyl} \sin^2\theta$) to the cylinder power.

Example 13.33

What is the "power" of a pl + 2.00 × 030 cylinder in the 180-degree meridian?

Solution

To find theta, we find the difference between the cylinder axis and the 180-degree meridian. This difference is the same as the axis of the cylinder (Figure 13.40). To find the "power" of the cylinder in the 180-degree meridian, we use the sine-squared formula.

By substitution we have:

$$\begin{aligned} F_\theta &= F_{cyl} \sin^2\theta \\ &= (+2.00) \sin^2 30 \\ &= (+2.00)(0.25) \\ &= +0.50\text{D} \end{aligned}$$

Therefore, the "power" of the cylinder in the 180-degree meridian is +0.50 D.

If the previous example represented a spherocylinder lens, we could add the sphere power to the "power" of the cylinder in the 180-degree meridian to find the full power of the spherocylinder in the 180-degree meridian. What about power in the 90-degree meridian?

It just so happens that, because of the mathematics of sines and cosines, the "power" of a plano-cylinder in the 90-degree meridian may be determined using the equation:

$$F_{90} = F_{cyl} \cos^2\theta$$

What if we want to know the full "power" of a spherocylinder lens in the 90-degree meridian? We do, in fact, want to know this power when figuring the amount of vertical imbalance between right and left lenses in the reading area. This imbalance can be corrected using a method called *slab-off*. In that case, the power of the spherocylinder lens in the 90-degree meridian could be determined using:

$$F_{90} = F_{sph} + F_{cyl} \cos^2\theta$$

This will be explained later in Chapter 21.

Lens Thickness in an Oblique Meridian

The sine-squared method for finding the curvature of a lens in an oblique meridian means we can find the radius of curvature in an oblique meridian. With radius of curvature and chord diameter, it is now possible to find sagittal depth in an oblique meridian. Sagittal depth in an oblique meridian leads directly to lens thickness in that oblique meridian. Thus, using sine-squared principles, we should be able to find lens thickness for any point on a lens. It is left as a challenge to the reader to take this concept further and find lens thickness for any given point on a lens.

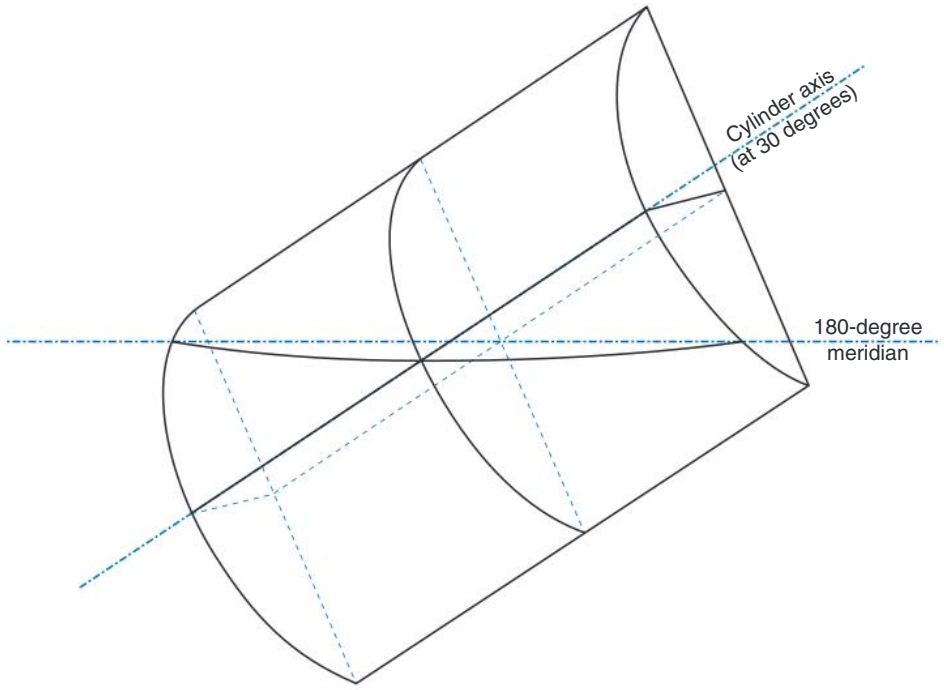


Figure 13.40 Finding the "power" of a plus cylinder lens in the 180-degree meridian can be visualized as shown in this figure.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

Lens Surface Powers and Base Curves

1. What is the base curve for a lens that has the following specifications?
   $F_1 = +7.25$ D
   F_2 at $90 = -6.00$ D
   F_2 at $180 = -8.00$ D
   a. −6.00 D
   b. −8.00 D
   c. +7.25 D
2. What is the base curve for a lens that has the following specifications?
   F_1 at $90 = +6.00$ D
   F_1 at $180 = +8.00$ D
   $F_2 = -7.00$ D
   a. +6.00 D
   b. +8.00 D
   c. −7.00 D
   d. −1.00 D
   e. +1.00 D
3. If the lens +3.00 + 1.00 × 180 is ground in minus cylinder form with the following dimensions, what is the toric, or back, base curve?
   $F_1 = +8.00$ D
   F_2 at $90 = -6.00$ D
   F_2 at $180 = -5.00$ D
   a. +8.00 D
   b. −6.00 D
   c. −5.00 D
4. If the lens +2.00 + 1.00 × 090 were to be ground in plus cylinder form with the F_2 surface being −4.00 D, what is the base curve?
   a. +6.00 D
   b. +7.00 D
   c. −4.00 D
   d. +2.00 D
   e. none of the above
5. True or false? *Base curve* and *toric base curve* are always synonymous terms.
   a. True
   b. False
6. True or false? It is unlikely that lenses today will be made in plus cylinder form. At present, almost all lenses are made in minus cylinder form.
   a. True
   b. False
7. A single-vision lens has a power of +5.25 − 2.25 × 120. If the lens is ground in minus cylinder form having a base curve of +6.00 D, what are the remaining two curves?
   a. +3.75 D and −0.75 D
   b. −0.75 D and −3.00 D
   c. +8.25 D and −3.00 D
   d. −3.75 D and −3.00 D
   e. none of the above
8. On the back surface of a lens having a plano front surface, a lens clock shows +1.25 in the 67-degree meridian and −1.75 in the 157-degree meridian. If the lens is made from a material with an index close to 1.53, what is the lens prescription?
   a. +1.25 − l.75 × 067
   b. −1.75 + 3.00 × 157
   c. −1.75 − 3.00 × 067
   d. +1.25 − 3.00 × 157
   e. none of the above

9. A lens clock reads as follows on the major meridians:

	Front Surface	Back Surface
In the 20-degree meridian	+8.00 D	−6.00 D
In the 110-degree meridian	+8.00 D	−7.00 D

Assuming that the lens material has an index close to 1.53, what is the prescription in minus cylinder form?
a. +2.00 − 1.00 × 110
b. +1.00 − 2.00 × 110
c. +2.00 − 1.00 × 020
d. +1.00 − 1.00 × 020

10. A lens surface has a refractive power of +8.25 D. If the lens is made from material having an index of 1.53, what is the radius of curvature of the lens surface in millimeters?
a. 15.6 mm
b. 18.5 mm
c. 30.7 mm
d. 64.2 mm

11. A lens surface has a refractive power of +8.25 D. If the lens is made from material having an index of 1.74, what is the radius of curvature of the lens surface?
a. 64.2 mm
b. 73.4 mm
c. 89.7 mm
d. 111.5 mm

12. You measure the front surface of a spherical polycarbonate lens with a lens clock. What are you measuring?
a. The nominal base curve
b. The true base curve
c. The refractive power of the surface
d. It is not possible to tell from the information given.

13. A lens has an index of refraction of 1.498 and a nominal base curve of +6.25. What is the true base curve?
a. +6.13
b. +6.20
c. +6.25
d. +6.33
e. cannot be determined from the information given

14. A lens of index 1.70 is ordered with a +8.25 D base curve. When it arrives, the base curve is checked with a lens clock and is found to be +8.17 D. What are the values for the nominal base curve, true base curve, and refractive power for this lens surface?
a. Nominal base curve = +8.17
True base curve = +8.25
Refractive power = +10.79 D
b. Nominal base curve = +8.17
True base curve = +8.25
Refractive power = +10.90 D
c. Nominal base curve = +8.25
True base curve = +8.17
Refractive power = +10.90 D
d. Nominal base curve = +8.25
True base curve = +8.17
Refractive power = +10.79 D

15. You would like to find the refractive power of several lens surfaces. All the surfaces are on lenses of index 1.67. You use a lens clock (lens measure) on the surface. This gives you a reference surface power but not the refractive power you are looking for. You could find the refractive power by using a conversion factor, multiplying your lens clock power by:
a. 0.791.
b. 0.916.
c. 1.092.
d. 1.264.
e. It is not possible to find surface refractive power in this manner.

16. True or false? A person comes in for an eye exam. The power of the prescription has increased slightly. When ordering the new pair of glasses, one should always check the base curve of the old glasses and order the same base curve for the new glasses.
a. True
b. False

17. True or false? An identically powered pair of glasses is ordered as a second pair using the same lens material. In this situation, it is advisable to check the base curve of the first pair and order the same base curve for the new glasses.
a. True
b. False

Crossing Cylinders and Spherocylinders

18. A ±1.00 D Jackson crossed cylinder is placed in a lensmeter. Written as a minus cylinder, what power would you expect to find?
a. +1.00 − 1.00 × something
b. −1.00 − 1.00 × something
c. +2.00 − 1.00 × something
d. +1.00 − 2.00 × something
e. −1.50 − 2.00 × something

19. A ±1.00 D Jackson crossed cylinder lens is oriented with powers placed horizontally and vertically. It is placed in front of a +2.00 D sphere lens. Which spherocylinder lens power could be a resultant of these two lenses?
a. +3.00 − 1.00 × 090 or 180
b. +2.00 − 2.00 × 090 or 180
c. +4.00 − 2.00 × 090 or 180
d. +2.00 − 1.00 × 090 or 180
e. +3.00 − 2.00 × 090 or 180

20. Give the sum of these two lenses: +2.00 − 2.00 × 090 and pl − 2.00 × 180. (Give your answer to the nearest quarter diopter.)
a. +2.00 − 4.00 × 045
b. +2.00 − 3.00 × 045
c. +2.00 sphere
d. pl − 2.00 × 090
e. 0.00

21. Give the sum of these two lenses: pl − 3.00 × 105 and pl − 3.00 ×075. (Give your answer to the nearest eighth diopter.)
a. pl − 5.25 × 180
b. −0.50 − 5.25 × 090
c. −0.50 − 5.25 × 180
d. pl − 3.25 × 090

22. Give the sum of these two lenses: pl − 3.00 × 015 and pl − 3.00 ×165. (Give your answer to the nearest eighth diopter.) Notice that this problem is the same as the previous problem except for the cylinder axes. Be careful in answering this. It is not as you might expect.
a. pl − 5.25 × 090
b. pl − 3.25 × 180
c. −0.50 − 5.25 × 180
d. −0.50 − 5.25 × 090

23. Give the sum of these two lenses: +3.00 + 1.50 × 110 and +2.00 + 2.25 × 130. (Give your answer to the nearest eighth diopter.)
    a. +7.00 + 2.12 × 126
    b. +5.00 + 3.62 × 119
    c. +4.62 + 3.25 × 124
    d. +5.00 + 3.75 × 118
    e. +5.12 + 3.50 × 122

The next three questions (Questions 24, 25, and 26) are based on the following text.

You order a toric soft contact lens having a power of −3.50 − 2.00 × 015.

The contact lens stabilizes and orients exactly as you expected it would. It is not rotated.

You do an overrefraction. Your results yield a power of +0.50 − 1.25 × 075.

You need to order another contact lens incorporating your overrefraction. What contact lens should you order? For sphere and cylinder power, order to the nearest quarter diopter; for cylinder axis, order to the nearest 5 degrees.

24. To the nearest quarter diopter, the correct sphere power is:
    a. −2.75.
    b. −3.25.
    c. −3.75.
    d. −4.25.
25. To the nearest quarter diopter, the correct cylinder power is:
    a. −1.00.
    b. −1.50.
    c. −1.75.
    d. −2.75.
26. The correct cylinder axis is:
    a. 035.
    b. 040.
    c. 060.
    d. 070.

You should not have to do any hard calculations for any of the following four questions (Questions 27 to 30). They are concept questions and should not require a calculator.

27. What would the resulting lens power be for a −2.00 − 1.00 × 090 lens and a −2.50 − 1.00 × 180 lens placed one on top of the other in a lensmeter?
    a. −2.25 − 1.00 × 045
    b. −4.50 − 2.00 × 045
    c. −4.50 DS
    d. −5.50 DS
    e. None of the above are correct responses.
28. What would the resulting lens power be for a −1.50 − 1.50 × 085 lens and a −3.00 − 1.50 × 005 lens placed one on top of the other in a lensmeter? (Give the answer rounded to the nearest eighth diopter that will be closest to the actual calculated values.)
    a. −4.50 − 3.00 × 045
    b. −4.50 − 1.50 × 045
    c. −5.75 − 0.50 × 045
    d. −6.00 − 1.50 × 045
    e. −6.00 DS
29. What would the resulting lens power be for a −1.50 − 1.50 × 050 lens and a −3.00 − 1.50 × 040 lens placed one on top of the other in a lensmeter? (Give the answer rounded to the nearest eighth diopter that will be closest to the actual calculated values.)
    a. −4.50 − 3.00 × 045
    b. −4.50 − 1.50 × 045
    c. −5.75 − 0.50 × 045
    d. −6.00 − 1.50 × 045
    e. −6.00 DS
30. What would the resulting lens power be for a −1.50 − 1.00 × 010 lens and a −2.50 − 1.50 × 020 lens placed one on top of the other in a lensmeter? (Give the answer rounded to the nearest eighth diopter that will be closest to the actual calculated values.)
    a. −4.00 − 2.50 × 016
    b. −4.00 − 2.50 × 015
    c. −4.00 − 2.50 × 014
    d. −2.00 − 1.25 × 015

Lens Thicknesses

(Read the next three questions [Questions 31, 32, and 33] carefully. They are not trick questions, but you do have to pay attention.)

31. A lens has a power of pl − 2.00 × 090. It is decentered 2 mm nasally and edged 50 mm round. Which edge is thickest?
    a. top and bottom
    b. nasal
    c. temporal
32. A lens has a power of +2.00 D sphere. It is decentered 2 mm nasally and edged 50 mm round. Which edge is thickest?
    a. top and bottom
    b. nasal
    c. temporal
33. A lens has a power of pl + 2.00 × 090. It is decentered 2 mm nasally and edged 50 mm round. Which edge is thickest?
    a. top and bottom
    b. nasal
    c. temporal
34. A lens has an index of refraction of 1.67. The lens is plano-concave in form. The power of the lens is −2.75 D sphere. The lens is to go into a horizontally oval frame with an A dimension of 48 mm and a distance between lenses (DBL) of 20 mm. The wearer's interpupillary distance (PD) is 66 mm. If the center thickness of the lens is 1 mm, what is the thickness of the thickest edge? (Choose the answer that is closest to the correct answer, even if you cannot find your exact answer.)
    a. 2.3 mm
    b. 2.9 mm
    c. 3.7 mm
    d. 4.2 mm
    e. 5.0 mm
35. A lens has a power of +2.00 − 4.00 × 180. It is edged 50 mm round and decentered 2 mm nasally. Which edge is thickest?
    a. top and bottom
    b. nasal
    c. temporal
36. A plano-convex round lens with no decentration is surfaced to a 50-mm diameter. It is surfaced until the edge has no thickness (a knife edge). The lens is made from polycarbonate (index 1.586). If the front surface of the lens has a radius of curvature of 95.1 mm, what is the center thickness of the lens? (Choose the closest answer.)
    a. 1.87 mm
    b. 14.2 mm
    c. 3.23 mm
    d. 3.34 mm

37. Using the Rule of Thumb for estimating lens thickness, estimate the expected edge thickness for the lens below. Assume the lens to be a crown glass or CR-39 lens. (There is more information given than is needed to answer the question.)
Power = −9.00 -D sphere
A = 50
DBL = 18
ED = 56
PD = 62
CT = 2.0
a. 6.3 mm
b. 6.9 mm
c. 8.1 mm
d. 8.3 mm
e. 10.1 mm

38. For the previous problem, what would the estimated edge thickness be if the lens had 3 Δ of base-out prism?
a. 7.1 mm
b. 8.6 mm
c. 10.1 mm
d. 11.6 mm
e. 13.1 mm

14

Optical Considerations With Increasing Lens Power

LENS POWER AS RELATED TO POSITION

The principal point of focus for a lens of a certain dioptric power is always the same distance from the lens for that lens power. So when the lens is moved, the point of focus moves as well. If the lens position needs to be changed but the focal point must stay in the same place, a new lens power is required.

Take the example of a camera. An older style camera will have film—a newer, an image sensor. For ease of understanding, we will use an example of an older style camera that uses film. If such a camera were to have a distance of +10 cm from the lens to the film, there is only one power of lens that will cause an object at infinity to focus exactly on the film. The proper lens power may be calculated if we know that the focal length of the lens must be +10 cm or +0.10 m.

Since

$$F = \frac{1}{f'}$$

then

$$F = \frac{1}{+0.10\,\text{m}} = +10.00\,\text{D}$$

If, however, the camera has a distance of +12.5 cm from lens to film, the +10.00 D lens is inappropriate since it would focus light 2.5 cm in front of the film, producing a blurry image. This is true whether the film moves or the lens moves. If the distance between lens and film changes from +10 to +12.5 cm, the power of the lens must be changed. To focus on the film at this new distance of +12.5 cm, a power of +8.00 D is required—less power than for the shorter distance (Figure 14.1).

Positional Lens Power Problems

Example 14.1

A lens of power +5.00 D is mounted so that it will focus light on a small screen. What new lens power will be required if the lens mounting is moved 5 cm farther away from the screen?

Solution

A +5.00 D lens has a focal length of +20 cm. For this reason, we know that the lens mounting was originally 20 cm away from the screen. If the mounting for the lens is moved 5 cm farther from the screen, the lens will now be 25 cm away from the screen. Therefore, to cause incoming parallel rays of light to focus on the screen, a lens with a focal length of +25 cm must be chosen. The reciprocal of 0.25 m is 4. Therefore, a +4.00 D lens must be chosen.

Example 14.2

Parallel light enters an optical system and must be made to diverge. A −12.50 -D lens gives the correct amount of divergence. The system is redesigned, and this lens must be moved 2 cm to the right (light is assumed to be traveling from left to right). According to the new system, the light must still diverge as if it were originating from the same point. What new lens power must be used at the new location to give the same effect?

Solution

The situation described is shown in Figure 14.2. In the old system, since the focal length of a −12.50 -D lens is −8 cm, light appeared as if it were coming from a point 8 cm to the left of the lens. The new system requires that this point be maintained, but the lens must now be 2 cm farther from it. The old lens may not be used since moving it 2 cm to the right would also move the focal point 2 cm to the right. To maintain the integrity of the system, the focal length of the new lens must be 2 cm longer than that of the old, which is 8 cm plus 2 cm, or 10 cm, to the left of the lens. The diverging lens that has a focal length of −10 cm has a refractive power of:

$$\frac{1}{-0.10\,\text{m}} = -10.00\,\text{D}$$

Effective and Compensated Powers

The power of a lens is normally designated by its dioptric power. Dioptric power depends on focal length. When light leaves the lens, the exiting light rays are parallel, converging, or diverging. The amount of convergence or divergence of light rays is a dioptric value. When in air, lenses get their dioptric power based on the reciprocal of the distance from the lens to the point of focus. However, as the light travels closer to the point of focus, its vergence value changes.

The vergence power a lens produces at a reference plane other than that occupied by the lens itself is known as the *effective power* of the lens. The effective power of a lens in air for a specific distance from the lens may be obtained by taking the reciprocal of the distance from the new reference plane to the focal point of the lens (Figure 14.3).

For example, if light rays are converging toward a given point in air, when these rays are 10 cm away from the point of focus, they have a

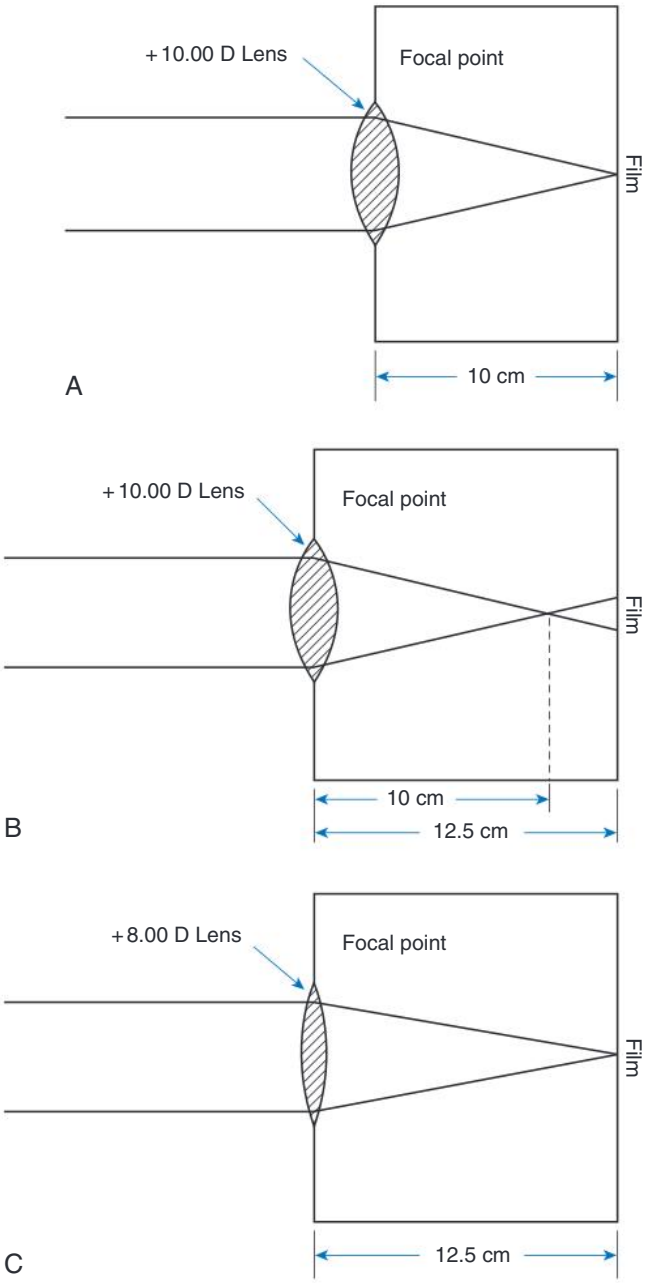


Figure 14.1 The relationship between lens power and desired focal plane may be illustrated using the example of an older style filmed camera. In **A**, the +10.00- D lens is correct for the camera's 10-cm depth. Placing that same lens in a deeper camera **(B)**, however, results in a blurred image. The lens is farther from the film, and the image falls short. Choosing a weaker lens with a longer focal length **(C)** resolves the problem.

vergence value of +10.00 D. At a reference plane 1 cm closer (9 cm or 0.09 m), the same rays now have a vergence value of:

$$\frac{1}{0.09\,\text{m}} \text{ or } +11.11\,\text{D}$$

Still another centimeter closer and the vergence will be:

$$\frac{1}{0.08\,\text{m}} \text{ or } +12.50\,\text{D}$$

Effective power helps us to understand why a prescription power may need to be modified when the spectacle lenses are to be worn at a different distance from the eyes than the refracting distance used during the refraction.

To help in understanding the reason for modifying lens powers, suppose the +10.00 D lens described above is to be replaced by a different lens positioned 2 cm to the right of the original +10.00 D lens. (Remember, the same focal point must be maintained.) Therefore, to have the same optical result as the +10.00 D lens, the example above shows how the replacement lens must be a +12.50 D lens.

As a second example, suppose a +10.00 D lens is to be replaced by a different lens positioned 5 cm to the right. To have the same optical result as the +10.00 D lens but at a position 5 cm to the right, a +20.00 D lens would be required (Figure 14.4).

Power as Related to Vertex Distance Changes

The distance from the back surface of the spectacle lens to the front surface of the wearer's eye is known as the *vertex distance*. Traditionally, for purposes of calculation, a refracting distance of 13.5 mm has been considered average. In practice, actual vertex distances for worn spectacles may vary considerably. Positioning the glasses at a vertex distance other than that used during refraction means that the power at the new spectacle plane is now different from the refracted and subsequently prescribed lens powers. For a low-powered lens, small changes in vertex distance will produce very little difference in dioptric power. Conversely, for a high-power lens, small changes in vertex distance will often yield considerable changes in needed power.

Example 14.3

Suppose a person were refracted at a 12-mm vertex distance and found to need a +8.50 D lens. A frame selection is made, and the lenses are fitted at a 17-mm vertex distance. (Incidentally, this is *not* a good frame selection for this prescription.) What compensated lens power must be used at 17 mm to give the intended power prescribed for the 12-mm refracting distance?

Solution

A +8.50 D lens has a focal length of +11.765 cm. If the new lens has a vertex distance of 17 mm, this is 5 mm to the left of the original position. To achieve the same optical result for the wearer, the focal length of the lens dispensed must be 5 mm longer than for the refracting lens.

$$+11.77\,\text{cm} + 0.50\,\text{cm} = +12.27\,\text{cm}$$

If the new focal length must be +12.27 cm, the new compensated lens power must be:

$$\frac{1}{+0.1227\,\text{m}} = +8.15\,\text{D}$$

(Note: Typically prescriptions are prescribed in quarter- or sometimes eighth-diopter increments. Adhering to these rounding traditions, the new power would be rounded to either +8.25 or +8.12 D for ordering. With the advent of digital surfacing, it is not inconceivable that a power might be ordered as +8.15 D. Even now, the position of wear progressive lenses will have the final prescription changed to conform to just such a vertex distance modification.)

Compensated Power of a Spherocylinder Lens

When calculating the new compensated power needed for a spherocylinder lens at an altered vertex distance, the power in each major meridian must be considered separately.

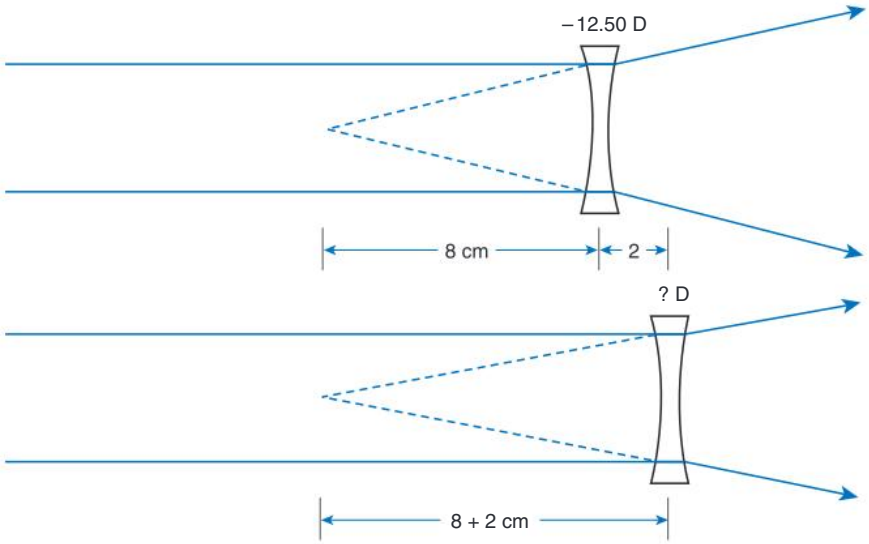


Figure 14.2 If the position of a lens changes, to maintain the same effect a lens of a different power must be chosen.

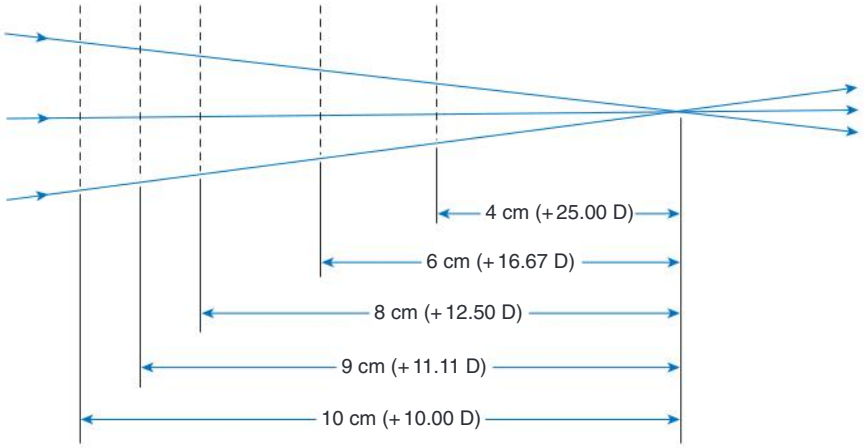


Figure 14.3 Vergence of light in air is the reciprocal of the distance in meters from the reference plane to the point of focus.

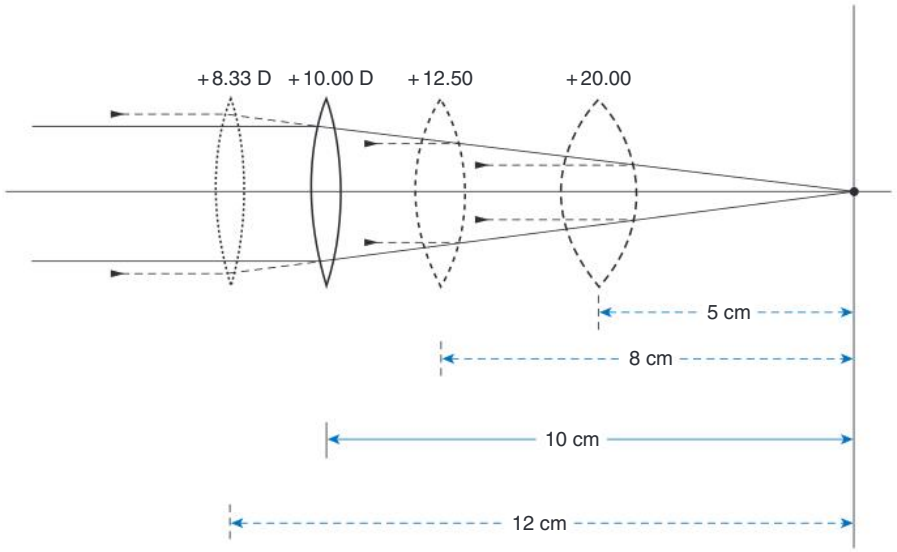


Figure 14.4 For different planes of reference, the optical effect of the original +10.00 D lens is different from the marked value. Thus, the *effective power* of a +10.00 D lens at a point 2 cm to the left of where it actually stands is +8.33 D. If the original +10.00 D lens was to be *replaced* by a different lens at this point 2 cm to the left of the original position so as to maintain the same intended focal point, that replacement lens would have a *compensated power* of +8.33 D.

Example 14.4

A +14.00 − 3.00 × 090 lens is prescribed at a 13.5-mm vertex distance. The frame selected is positioned at 10 mm. What should the new prescription be?

Solution

The major meridian powers are:

$$F_{180} = +11.00\,\text{D}$$
$$F_{90} = +14.00\,\text{D}$$

The new compensated power for the 180-degree meridian is calculated by first finding the focal length:

$$f'_{180} = \frac{1}{+11.00} = +0.0909\,\text{m} = +9.09\,\text{cm}$$

The new lens will be 13.5 − 10, or 3.5 mm, closer to the line foci of the lens. Therefore, since the lens is plus, the focal lengths will be 3.5 mm shorter.

$$\text{New } f'_{180} = +9.09\,\text{cm} - 0.35\,\text{cm} = +8.74\,\text{cm}$$

So the new F_{180} is:

$$F_{180} = \frac{1}{+0.0874\,\text{m}} = +11.44\,\text{D}$$

Now we find the new power in the 90-degree meridian: Since

$$F_{90} = +14.00\,\text{D}$$

then

$$f'_{90} = \frac{1}{+14.00} = 0.0714\,\text{m} = +7.14\,\text{cm}$$

Again since the lens power is plus, the focal length in the 90-degree meridian will be 3.5 mm or 0.35 cm shorter, so

$$\text{New } f'_{90} = +7.14 - 0.35 = +6.79\,\text{cm}$$

This means that the new focal length in the 90-degree meridian is:

$$F'_{90} = \frac{1}{+0.0679\,\text{m}} = +14.73\,\text{D}$$

If the new $F_{180} = +11.44$ D and the new $F_{90} = +14.73$ D, then the new cylinder power is the difference between the two meridian powers.

$$14.73 - 11.44 = 3.29$$

When written in minus cylinder form, the new compensated lens power will be +14.73 − 3.29 × 090. Not only has the sphere power changed but also the power of the cylinder. These prescription powers would be rounded, making the prescription +14.75 − 3.25 × 090.

It is *not* valid to calculate a compensated power for the cylinder based on a −3.00 D power. The new cylinder value is the *difference* between the two recalculated major meridians and is not an independent entity.

Compensated Power Written as a Formula

Compensated power can be found using a formula. The formula is:

$$F_C = \frac{1}{\frac{1}{F_v'} - d}$$

where F_C is the compensated power at the new reference plane, F_v' is the back vertex power of the prescribed lens, and d is the difference in meters between the original position of the prescribed lens and the new position of the compensated lens.

- If the compensated lens will be closer to the eye, d is a positive number and, according to the formula, is subtracted.
- If the compensated lens will be farther from the eye (moved in a minus direction), d is a negative number. (Remember, if d is negative and is also subtracted, it is really being added. Minus a minus is a plus.)

The above formula for compensated power may also be seen written as:

$$F_C = \frac{F_v'}{1 - dF_v'}$$

Both are the same. The second formula is simply a transposed form of the first formula.

Though a formula is easier to use in the short run, it is not advisable to simply memorize the formula. Instead, try to understand the concept of compensated power first. Then using the formula is an acceptable method.

AS LENS THICKNESS INCREASES

As a lens becomes thicker, there is an increase in the distance between the front and back surfaces. Changing the position of the second lens surface with respect to the first means that the effective power of the first surface at the plane of the second surface is not the same. This in turn causes a change in total lens power. The actual amount of change may be calculated using vergences.

How Vergence Changes in Higher Index Materials

In Chapter 12, the concept of vergences was introduced. It was also used earlier in this chapter when talking about the effective power of a lens. In both cases, when vergence changes occurred, they occurred in air. Because the index of air equals 1, the vergence value was always the inverse, or reciprocal, of the distance in meters from the reference plane to the point of focus. This was shown in Figure 14.3. But how does vergence change when light is converging or diverging in a medium of higher index?

When Light Leaves a Lower Index and Enters a Higher Index

Suppose light traveling in air is converging. As it converges, it strikes a thick slab of plastic of index 1.5. The surface of the plastic is flat. When the light strikes the plastic, it has a vergence of +5.00 D (Figure 14.5). When it enters the plastic, the light rays change their angle because of Snell's law. Even though the angle changes, the vergence of the light does not change because the entering surface is flat, having no power. We know that the Fundamental Paraxial Equation is $F = L' - L$. By transformation of the equation, we know that:

$$L + F = L'$$

In our example, since $F = 0$, then

$$+5.00 + 0 = L'$$

so

$$L' = +5.00$$

However, even though the vergence has not changed, the distance from the flat surface to the point where the light comes to a focus in the new index does change. In air, the light would have come to a point focus at +0.20 m from the flat surface. But in 1.5 index plastic, it instead comes

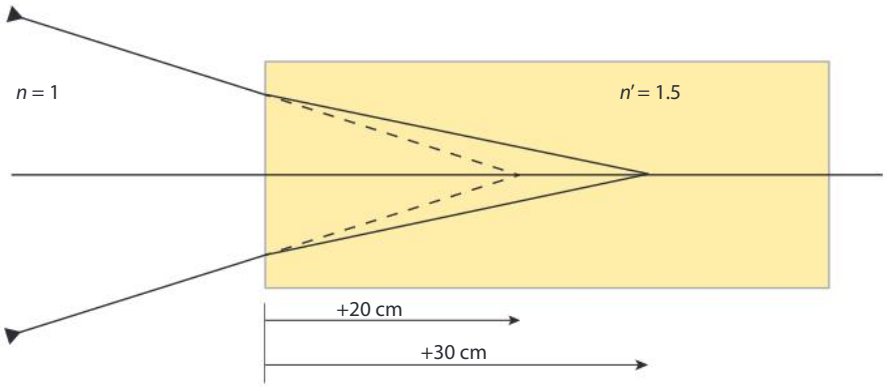


Figure 14.5 When light is traveling from a lower to a higher index medium, light bends toward the normal. The refracting surface is flat, having a zero-refracting power. The incoming light strikes the surface with a vergence of +5.00 D. It also leaves that same flat surface with a vergence of +5.00 D. Because of the index change, the direction of the rays also changes. Instead of focusing at +20 cm from the reference surface, the rays focus at +30 cm from the reference surface.

to a focus at a greater distance away from the surface. That distance is found as follows:

$$L' = \frac{n'}{l'}$$

$$+5.00 = \frac{1.5}{l'}$$

$$l' = \frac{1.5}{+5.00} = +0.30\,\text{m} = +30\,\text{cm}$$

When Light Leaves a Higher Index and Enters a Lower Index

Now we will look at the situation where light is leaving a higher index and entering a lower index. Consider the familiar situation of someone looking into an aquarium. Here light is leaving the higher index of water (index 1.33) and entering the lower index of air (index 1.00).

Example 14.5

Suppose the aquarium is 100 cm from front to back. The observer is standing in front of the aquarium looking at a snail on the back surface (Figure 14.6). How far away from the front surface will the snail appear to be? (The question really asks, "What effect will the refractive index of water have on the perceived distance from the front to the back of the fish tank compared with what it would look like without water in the tank—just air?")

Solution

We can assume that the aquarium glass separating the air and water is thin enough to be of no concern in calculations. The situation is one in which light leaves the object while in water (a snail), and diverges for 100 cm until it reaches the new refractive surface of air at the front of the aquarium. Since the front side of the aquarium is flat, the refracting surface has zero power.

$$F = 0.00\,\text{D},$$

$$l = -100\,\text{cm or} -1.0\,\text{m},$$

$$n = 1.33, \text{and}$$

$$n' = 1.00$$

Since the right surface of the tank is the reference refracting surface, the distance from the snail to the front aquarium surface (l) is taken as being a minus distance. Light is traveling left to right from the snail, through the water, to the right side of the tank. So light is traveling first through water (n) before it reaches the surface of the tank.

The equation $L + F = L'$ is written as:

$$\frac{n}{l} + F = \frac{n'}{l'}$$

Entering the values already known results in:

$$\frac{1.33}{-1.0} + 0 = \frac{1}{l'}$$

which algebraically transforms to:

$$l' = \frac{-1}{1.33} = -0.75\,\text{m}$$

So the snail and the back surface of the tank appear to be −0.75 m or −75 cm from the front surface.

This example clearly shows that the light entering *and* leaving the right surface of the aquarium has the same vergence even though the light bends at the surface because of the change in refractive index. If $F = 0$, then $L = L'$. The distance in water as compared with that in air appears reduced because the light is traveling more slowly in water than in air. This concept is referred to as *reduced thickness*. Transparent objects of a higher refractive index than air appear thinner than they are when compared with the equivalent distance in air. The relationship between the reduced thickness, the actual thickness (t), and the index of the medium in question (n) can be stated as:

$$\text{Reduced thickness} = \frac{t}{n}$$

Vergence Changes as Light Travels Through a Lens

When light strikes a lens, it is refracted at the front surface and then travels through the thickness of the lens. As light travels through the thickness of the lens, its vergence changes. The vergence of light is changed again when refracted by the back lens surface. For thin lenses, the distance traveled from front to back surfaces makes no appreciable change in the vergence of the light, so there is not a noticeable change in total lens power. The thicker the lens becomes, however, the more of a

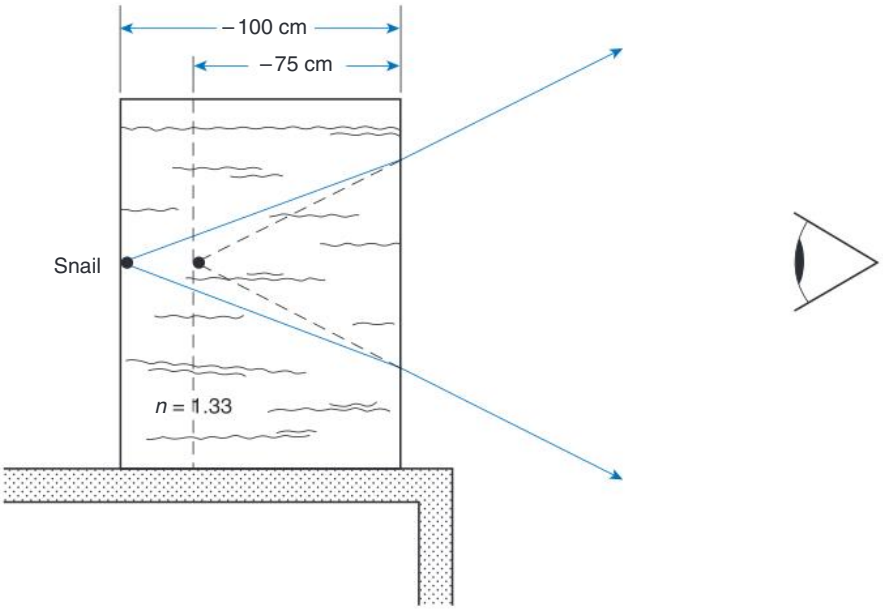


Figure 14.6 The most familiar example of reduced thickness is seen with an ordinary aquarium. Looking at the contents of the aquarium through water makes individual objects seem to be closer than they would otherwise appear if viewed only through air.

discrepancy there is between nominal (approximate) power ($F_1 + F_2$) and the back vertex power of the lens.

For Thin Lenses

For a thin lens, when the vergence of the entering light is zero (parallel rays), the light exiting the lens will have a vergence equal to the dioptric powers of the first and second lens surfaces ($F_1 + F_2$).

For example, for a thin lens, if $F_1 = +5.00$ D and $F_2 = +1.00$ D, what is the vergence of light leaving F_2, the back surface of the lens?

The solution is a simple one. When parallel light strikes F_1, it is made to converge. It now has a vergence of +5.00 D. Because the lens is thin, light immediately strikes the back surface before its vergence has a chance to significantly change. Now the back surface (F_2) causes light to converge an additional +1.00 diopter. So, on leaving the second surface of the lens (F_2), the light now has a vergence of +6.00 D.

For Thick Lenses

For a thick lens, the converging light leaving the first surface would have a chance to travel a significant distance before reaching the second surface (F_2). By the time light reaches the second surface, F_2, it will have a different vergence value from what it had when it left the first surface, F_1. It is this *new* vergence (the effective power of F_1 at F_2) that is then passed through the second surface to produce the final vergence leaving the lens. With thick lenses, vergence is affected by both the thickness of the lens and the refractive index of the lens material.

Using Reduced Thickness to Find Thick Lens Power

For a thick lens, light enters the front surface of the lens, traverses through, and then enters the back surface. Initially, one would think that the vergence entering the second surface of the lens would be found by directly adding or subtracting lens thickness from the image distance of light leaving the first surface. But because the index between the front and back surfaces is not air, this does not work. It is instead necessary to find the new vergence at F_2 by adding or subtracting the *reduced thickness* of the lens from the reciprocal of the vergence. Compensating for the index allows us to keep the reference medium as air. This is helpful and makes calculations easier when the final results are for light rays leaving the lens and entering into air. (Note: There are other valid ways to calculate thick lens power problems other than by using reduced thicknesses. Thick lens powers may be calculated using front or back vertex power formulas or using changes in vergence as light progresses through the lens.)

Example 14.6

Parallel light enters a 7-mm thick crown glass lens that has a front surface power of +12.00 D and a refractive index of 1.523. What vergence will the light have by the time it reaches the back surface (F_2)?

Solution

After leaving F_1, the light has a vergence that can be calculated from:

$$F_1 = L_1' - L_1$$

Substituting the correct numerical values, we find that:

$$+12.00\,\text{D} = L_1' - 0$$

or

$$L_1' = +12.00\,\text{D}$$

Light leaving the front surface (F_1) has a vergence of +12.00 D.

The light is now converging toward a point to the right of the front surface. That point in air would be found by taking the reciprocal of the vergence.

$$L_1' = \frac{1}{l_1'}$$

and

$$+12.00 = \frac{1}{l_1'}$$

$$l_1' = +0.0833\,\text{m}$$

The distance in question is +0.0833 m.

The light must travel through glass for 7 mm before reaching air, however. To find the vergence of light at F_2, the *reduced thickness* of this lens must be subtracted from l_1' because the point of focus is now closer to the new plane of reference, which is the back surface of the lens.

Therefore, the new distance (l_2) is:

$$l_2 = l_1' - \frac{t}{n}$$

where t/n is the reduced thickness of the lens. (Thickness must be expressed in the same units as l_1'.) We continue by finding l_2.

$$\begin{aligned} l_2 &= 0.0833\,\text{m} - \frac{0.007\,\text{m}}{1.523} \\ &= 0.0833\,\text{m} - 0.0046\,\text{m} \\ &= 0.0787\,\text{m} \end{aligned}$$

The vergence of the light entering the back surface (F_2) is the reciprocal of 0.0787 m.

$$\begin{aligned} L_2 &= \frac{1}{l_2} \\ &= \frac{1}{0.0787} \\ &= +12.71\,\text{D} \end{aligned}$$

So the vergence of light entering F_2 is +12.71 D. It can be seen from the above example that if F_2 were flat, having zero power, the vergence of light leaving F_2 would not change and would still be +12.71 D. This is +0.71 D stronger than if the lens power were simply assumed to be the sum of the two lens surface powers.

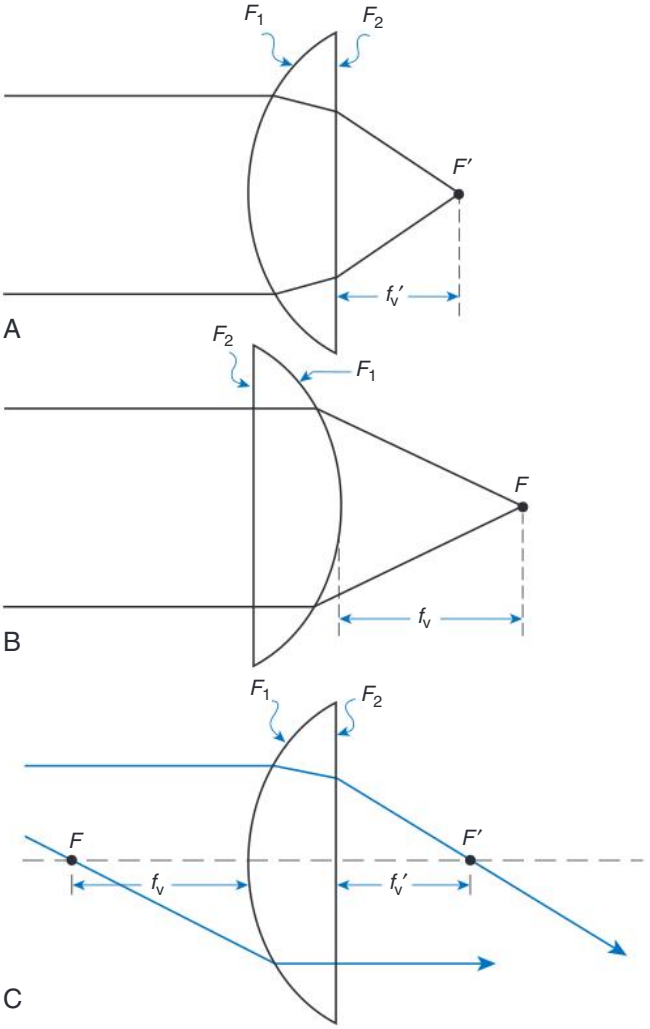


Figure 14.7 When light enters a lens from the front, the focal length and, consequently, the measured focal power can be different from when light enters a lens from the back. **A** and **B** show the difference between front vertex and back vertex focal lengths (f_v and f_v'). These focal lengths will directly determine front and back vertex focal powers (F_v and F_v'). (It is important to note the orientation of the lens shown in **B.** The lens is intentionally drawn backward to allow a better visual comparison between the front and back vertex focal lengths.) **C** shows the conventional manner of representing front and back vertex focal lengths diagrammatically. *F*, First principal focal point; *F′*, second principal focal point; f_v , front vertex focal length; f_v' , second vertex focal length.

FRONT AND BACK VERTEX POWERS

It has been shown that because of lens thickness, the nominal or approximate power of a lens does not accurately predict the power of the lens. Recall that when parallel light enters the front of a lens, it is refracted and exits from the rear surface of the lens. The image, be it real or virtual, falls at the *second principal focus.*

The reciprocal of the distance in air from the rear surface of the lens to the second principal focus is a specific measure of the power of this lens and is known as the *back vertex power* (F_v'). (This is the measure of power of most importance in ophthalmic lenses.)

(Note: Chapter 6 has information on how to measure lens power using the lensmeter. The material found there is relevant to this section as well.)

If light leaves the back surface of the lens parallel, with zero vergence, the place from which the light originated is known as the *first principal focus.* (This is the same thing as saying that if parallel light were to enter the lens from the rear surface, the place where the image would be formed is known as the *first principal focus.* Remember, even though we normally consider light as traveling from left to right, it is reversible and would travel the same path right to left.) The reciprocal of the distance in air from the front surface of the lens to the first principal focus is another measure of the power of the lens. This measure is referred to as the *front vertex power* (F_v) (Figure 14.7). It is not unusual to find front and back vertex powers to be different. If the lens is equiconcave or equiconvex, the front and back vertex powers will be the same. But if the lens has any other form and is thick, there is likely to be a measurable difference between front and back vertex powers.

Calculating Front and Back Vertex Powers

Front and back vertex powers may be found by finding vergence as light approaches and leaves each lens surface. They may also be found using a formula summarizing the necessary vergence factors. By following the vergence methods for solving this type of problem, it will result in a much better understanding of the action of a lens on light than will simple formula memorization. Both methods are described.

Solving for Front and Back Vertex Powers Using Vergence

If light enters the front surface of a lens as parallel rays, the back vertex power of a lens will be equal to the vergence these light rays have when

they leave the back surface of the lens. If the form, thickness, and refractive index of that lens are known, the back vertex power may be found by systematically tracing the path light rays take through the lens.

Example 14.7

A lens has the following dimensions:

$$F_1 = +8.00\,\text{D}$$
$$F_2 = -2.00\,\text{D}$$
$$t = 5\,\text{mm}$$
$$n = 1.523$$

What is the back vertex power of the lens?

Solution

Light entering the lens must be from an object at infinity to determine back vertex lens power. The rays entering the front surface of the lens will then be parallel, having a vergence of zero (Figure 14.8). Since

$$L_1' = F_1 + L_1$$

and

$$L_1 = 0.00\,\text{D}$$

then

$$L_1' = +8.00\,\text{D} + 0.00\,\text{D}$$

or

$$L_1' = +8.00\,\text{D}$$

To find the vergence of light at F_2, the reduced thickness is first subtracted from l'_1.

$$\begin{aligned} l_2 &= l'_1 - \frac{t}{n} \\ &= \frac{1}{+8.00} - \frac{0.005\,\text{m}}{1.523} \\ &= 0.125\,\text{m} - 0.0033\,\text{m} \\ &= 0.1217\,\text{m} \end{aligned}$$

Therefore, the vergence of light at the back surface is:

$$L_2 = \frac{1}{l_2} = \frac{1}{0.1217} = +8.22\,\text{D}$$

(This is the same procedure as finding the effective power of F_1 at the F_2 plane.)

Now, since

$$L_2' = F_2 + L_2$$

then in this case,

$$L_2' = -2.00 + 8.22 = +6.22$$

Since back vertex power is the vergence with which light from an object at infinity leaves a lens, the back vertex power (F_v') for this lens is +6.22 D. This is noticeably different from the nominal power of the lens, which is +6.00 D.

Example 14.8

What would the front vertex power be for the lens described in the previous problem?

Solution

To simplify the construction, it is easier to find the front vertex power by turning the lens around and considering light to be entering from the back as was shown in Figure 14.7, *B*. In this manner, sign conventions are maintained, and less confusion results. The same methodology may be used as in finding the back vertex power, F_v'. To prevent confusion in terminology, the back surface of the lens now becomes F_1 (since light now enters it as if it were the front surface), and the front surface will become F_2 (Figure 14.9).

$$L_1' = F_1 + L_1$$

Now, $L_1 = 0.00$ D, and the new $F_1 = -2.00$ D. So:

$$L_1' = -2.00\,\text{D} + 0.00\,\text{D} = -2.00\,\text{D}$$

Again, the vergence of light at F_2 is found by first subtracting reduced thickness from l'_1.

$$\begin{aligned} l_2 &= l'_1 - \frac{t}{n} \\ &= \frac{1}{-2.00} - \frac{0.005}{1.523} \\ &= -0.5000\,\text{m} - 0.0033\,\text{m} \\ &= -0.5033\,\text{m} \end{aligned}$$

Converting this distance into vergence gives:

$$L_2 = \frac{1}{l_2} = \frac{1}{-0.5033\,\text{m}} = -1.99\,\text{D}$$

Now,

$$\begin{aligned} L_2' &= F_2 + L_2 \\ &= +8.00\,\text{D} - 1.99\,\text{D} \\ &= +6.01\,\text{D} \end{aligned}$$

The front vertex power for this lens is +6.01 D. This is extremely close to the nominal power of the lens. If the surface of the lens that light was entering had been plano, this vertex power would have been equal to the nominal power. The more curved the entering surface, the more the vertex power of the lens will differ from its nominal power.

Solving for Front and Back Vertex Powers Using Formulas

The previous vergence methods may be summarized into formulas. The formula for back vertex power is:

$$F_v' = \frac{F_1}{1 - \frac{t}{n}F_1} + F_2$$

And the formula for front vertex power is:

$$F_v = \frac{F_2}{1 - \frac{t}{n}F_2} + F_1$$

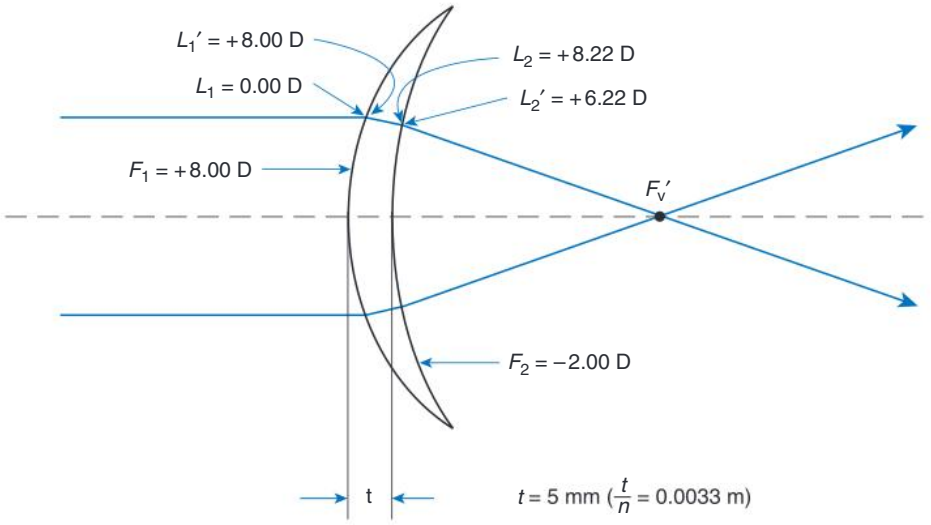


Figure 14.8 Lens curvature and thickness have a definite bearing on the final back vertex power of a lens.

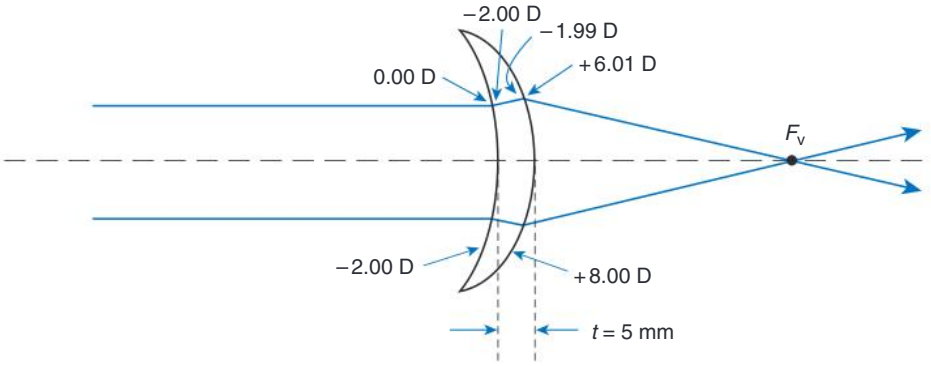


Figure 14.9 Reversing a lens may change the position of the image. For some lenses, front and back vertex power may be quite different. Here, the lens shown in Figure 14.8 has been reversed to more easily use a vergence method of finding its vertex power.

The above formulas give results that are accurate and identical to those found by the vergence method using reduced thicknesses.

Which Powers Will Be Greater?

To summarize,

- *Nominal power.* The nominal power of a lens is the sum of the two surface powers. Nominal power does not take lens thickness into consideration.
- *Back vertex power.* When parallel light enters the front of the lens, the back vertex power is the vergence value of the light as it leaves the back surface of the lens. By convention, this is the power used when specifying the power of a spectacle lens.
- *Front vertex power.* The front vertex power of the lens is equal to the vergence value of light entering the front surface of the lens that will produce parallel light when it leaves the back surface.

How will these powers compare in magnitude? For thick lenses, the answer depends upon whether the lens is biconvex, biconcave, or meniscus. Since most spectacle lenses are made as meniscus-form lenses (i.e., convex on the front and concave on the back), this allows for a predictable pattern of relative powers based on the following two principles:

- As we saw with effective power, converging or diverging light rays gain plus (or lose minus) power as they travel. This includes all light rays gaining plus (or losing minus) while traveling the thickness of an ophthalmic lens. For this reason, the back and front vertex powers of thick meniscus-form lenses will always be more plus (or less minus) than nominal powers, which do not consider lens thicknesses.
- In meniscus lenses, the back vertex power will always have a higher magnitude power than the front vertex power. As the lens thickness becomes greater, the disparity between back and front vertex powers will also become greater.

Therefore, for plus meniscus lenses, the nominal power is the least plus, the front vertex power is slightly more plus, and the back vertex power is the most plus. For minus meniscus lenses, the front vertex power is the least minus, the back vertex power is more minus, and the nominal power is the most minus.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. A lens has a back vertex power of +8.00 D. Light enters the front surface parallel, and it begins to converge as it leaves the back surface. What is the vergence of the converging light at a plane 2.5 cm to the right of the back surface of the lens? (Another way of asking this question would be "What is the effective power of this lens at a plane 2.5 cm to the right of the lens?")
   a. +40.00 D
   b. +12.50 D
   c. +10.00 D
   d. +6.67 D
   e. +5.50 D
2. A lens has a back vertex power of −8.00 D. Light enters the front surface parallel, and it begins to diverge as it leaves the back surface. What is the vergence of the diverging light at a plane 2.5 cm to the right of the back surface of the lens? (Another way of asking this question would be "What is the effective power of this lens at a plane 2.5 cm to the right of the lens?")
   a. −15.00 D
   b. −12.50 D
   c. −10.00 D
   d. −6.67 D
   e. −5.50 D
3. If a +11.00 D lens is worn at a 13-mm vertex distance, to what power must the spectacle prescription be changed if it is to be worn at a 10-mm vertex distance? (Give the answer to the nearest eighth diopter.)
   a. +10.62 D
   b. +10.75 D
   c. +11.25 D
   d. +11.37 D
   e. +11.50 D
4. A prescription for a very high minus lens reads:
   O.D. −27.50 DS
   O.S. −27.50 DS
   Refracting distance 14 mm.
   If the glasses were to be worn at a vertex distance of 11 mm, what would the compensated lens powers be? (Give the answer to the nearest eighth diopter.)
   a. −25.12 D
   b. −25.37 D
   c. −25.62 D
   d. −30.00 D
   e. −30.62 D
5. If a person with a high minus spectacle prescription switches to contact lenses, the power in the contact lens would be _____ the power in the spectacle lens.
   a. greater than
   b. less than
   c. the same as
6. A person's eyes were examined at a vertex distance of 14 mm and found to require a +8.50 D sphere power. A frame having a vertex distance of 11 mm is desired. If the glasses are to be worn at 11 mm, what must the compensated power of the lens be to give the same visual correction? (Round to the nearest eighth diopter.)
   a. +8.25 D
   b. +8.37 D
   c. +8.62 D
   d. +8.75 D
   e. +8.87 D
7. A prescription of −9.25 −3.25 × 015 is determined using a refracting vertex distance of 13.5 mm. If the frame is fit for a 10-mm vertex distance, what must the theoretical power of the lens be? (Round both sphere and cylinder powers to the nearest quarter diopter.)
   a. −9.00 −3.25 × 015
   b. −9.00 −3.00 × 015
   c. −9.25 −3.25 × 015
   d. −9.50 −3.50 × 015
   e. −9.50 −3.25 × 015
8. A slab of plastic with an index of refraction of 1.67 is 10.0 mm thick. The speed of light slows as it enters a medium of higher index. What is the reduced thickness for this slab of plastic?
   a. 7.50 mm
   b. 6.7 mm
   c. 6.6 mm
   d. 6.5 mm
   e. 6.0 mm
9. If a single-vision lens is placed in the lensmeter in the reverse position (concave side toward the observer), the power value obtained is a measure of
   a. equivalent power.
   b. effective power.
   c. back vertex power.
   d. front vertex power.
   e. true power.
10. A thick lens has a convex front surface and a plano back surface. Which of the following statements about this lens is true?
    a. The front vertex power is greater than the back vertex power.
    b. The back vertex power is greater than the front vertex power.
    c. Front and back vertex powers will be equal.
    d. None of the above are true.
11. Using vergences or the back vertex power formula, find the back vertex power for a lens ground to the following specifications.
    Front surface curve: +13.00 D
    Back surface curve: plano
    Center thickness: 10 mm
    Index of the lens: 1.5
    a. +14.23 D
    b. +14.12 D
    c. +13.87 D
    d. +13.50 D
    e. +13.00 D
12. A lens has the following dimensions:
    $F_1 = +8.00$ D
    $F_2 = -1.00$ D
    $n = 1.70$
    $t = 5$ mm
    What is the *front* vertex power of the lens?
    a. +7.00 D
    b. +7.12 D
    c. +7.25 D
    d. +7.37 D
    e. +7.50 D
13. When measured with a lens clock, a lens having an index of 1.53 measures as +10.00 D on the front surface and plano on the back surface. The lens is 6 mm thick. What is the difference between the nominal power and the back vertex power of the lens?
    a. 0.55 D
    b. 0.41 D
    c. 0.26 D
    d. 0.04 D
    e. The nominal and back vertex powers are equal.

14. A lens has a front surface power of +8.00 D. Assume that it will be ground 5 mm thick from material of refractive index 1.5. To obtain a *back vertex power* (F_v') of +2.00 D, what power must the back surface of the lens have?

a. −10.22 D
b. −10.91 D
c. −8.91 D
d. −6.91 D
e. −6.22 D

15. A lens is thick, high plus in power, and meniscus in form. The prescription has a cylinder component. To obtain the same back vertex power so that the cylinder comes out correctly as indicated by the prescription, which of the following statements is true?

a. If the cylinder were to be ground on the front surface, it would need to be greater in power than the cylinder value indicated in the prescription.
b. If the cylinder were to be ground on the front surface, it would need to be less in power than the cylinder value indicated in the prescription.
c. If the cylinder were to be ground on the front surface, it would need to be the same power as the cylinder value indicated in the prescription.

15

Optical Prism: Power and Base Direction

OPHTHALMIC PRISMS

A prism consists of two angled refracting surfaces. The simplest form of a prism is two flat surfaces that come together at an angle at the top. The point is called the *apex* of the prism; the wider bottom of the prism is called the *base*.

The Relationship Between Prism Apical Angle and Deviation of Light

Suppose a prism is oriented so that incoming light strikes the first surface perpendicularly. When light strikes the first surface, it is going from a lower refractive index material (air) into a higher refractive index material (the prism). However, it does not change direction because it enters the surface straight on. Light will continue to travel through the prism without being bent until it reaches the second surface (Figure 15.1). This ray of light then strikes the second surface at an angle. *Because the light has not been bent by the first surface, the angle at which it strikes the second surface is equal to the apical angle of the prism* (Figure 15.2). As this ray of light approaches the second surface of the prism, it is traveling from the denser (higher refractive index) medium of the prism to a lesser dense medium (air) and will be bent away from the *normal* to the surface. (Remember, if light enters "*normal*" to the surface, that means it is entering perpendicular to the surface.) Light is bent toward the base of a prism.

What is the relationship between the apical angle of a prism and the amount of deviation of the light produced by that prism?

Example 15.1

If a prism has an apical angle of 8 degrees and is made from CR-39 plastic with a refractive index of 1.498, how many degrees will the prism deviate the light ray from its original path?

Solution

When working through this example problem, refer to Figure 15.2. Notice that light entering the first surface is perpendicular to the surface and is not bent. It is bent at the second surface and, according to Snell's law,

$$n \sin i = n' \sin i'$$

$$\text{where } n = 1.498$$

$$n' = 1.0$$

$$\sin 8 = 0.1392$$

So, by substituting,

$$(1.498)(0.1392) = (1.0)(\sin i')$$

$$\sin i' = 0.2085$$

Next, using a calculator, we find the inverse sine ($\sin^{-1}$) of 0.2085 to be:

$$i' = 12.03 \text{ degrees}$$

The angle of refraction is the angle at which the light ray leaves the second surface. To find the angle of deviation (i.e., how many degrees the light is deviated from its original path), subtract the angle of incidence from the angle of refraction.

$$\text{(Angle of deviation)} = \text{(Angle of refraction)} - \text{(Angle of incidence)}$$

$$d = i' - i$$

$$= 12.03 - 8.00$$

$$= 4.03 \text{ degrees}$$

In this instance, the resulting angle of deviation is 4.03 degrees, or, rounded off, 4.0 degrees.

Example 15.2

A prism is made from polycarbonate material having an index of 1.586. It has an apical angle of 5 degrees. What is the angle of deviation that it produces in air?

Solution

Again using Snell's law,

$$n \sin i = n' \sin i'$$

We can substitute and find:

$$(1.586)(\sin 5) = (1.0)(\sin i')$$

$$(1.586)(0.0872) = \sin i'$$

$$\sin i' = 0.1382$$

Next, the inverse sine of 0.1382 is found.

$$i' = 7.95 \text{ degrees}$$

The angle of deviation is:

$$d = i' - i$$

$$= 7.95 - 5$$

$$= 2.95 \text{ degrees}$$

So, the angle of deviation is 2.95 degrees.

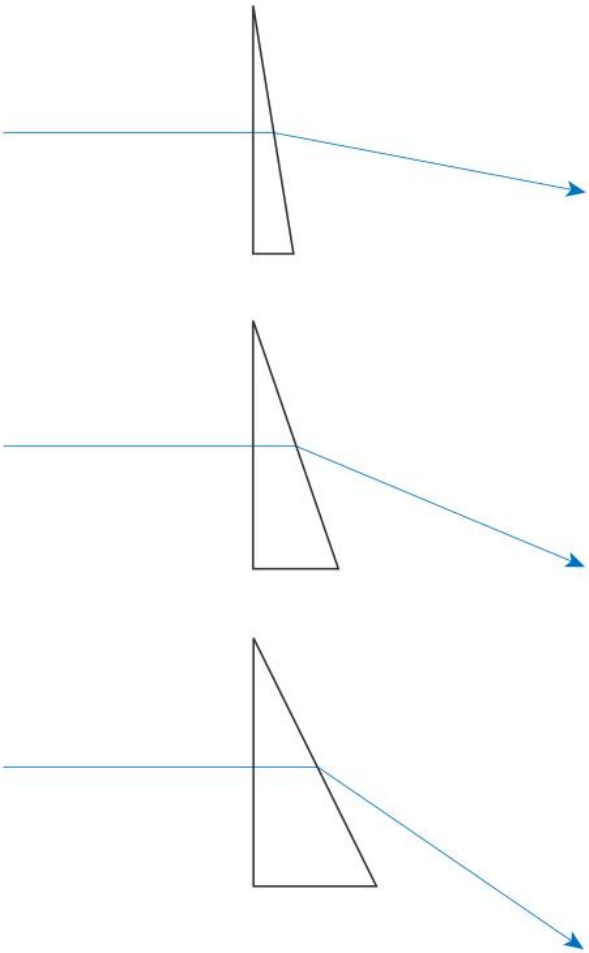


Figure 15.1 The more wedge shaped a prism is, the greater is its ability to divert light in another direction.

Simplifying for Thin Prisms

In an effort to simplify, there is a shortcut for finding the angle of deviation that may be applied for thin prisms.

We know by looking at Figure 15.2 that:

- The angle of incidence (i_2) equals the apical angle of the prism (a) or ($i_2 = a$).

The angle of refraction (i_2') is the sum of the apical angle (a) plus the angle of deviation (d) or

$$(i_2' = a + d)$$

This means that if we begin with:

$$n \sin i_2 = n' \sin i_2'$$

We can substitute and get:

$$n \sin a = n' \sin (a + d)$$

When angles are small (10 degrees or less), the sine of the angle is the same as the angle measured in radians. If this is the case, it is possible to say that:

$$(n)(a) = (n')(a + d)$$

Because the prism is in air, $n' = 1$ and the equation becomes:

$$(n)(a) = (a + d)$$

To find the angle of deviation, d, we can transpose the equation and get:

$$d = (n)(a) - a$$

or, written another way,

$$d = a(n - 1)$$

For this equation, it does not matter if the angle is in radians or degrees. It still works. So, for prisms with an apical angle of less than 10 degrees, the angle of deviation equals the apical angle times the quantity "index minus 1." (Remember that this formula is an accurate approximation for thin prisms only but quickly loses accuracy once a prism increases in thickness.)

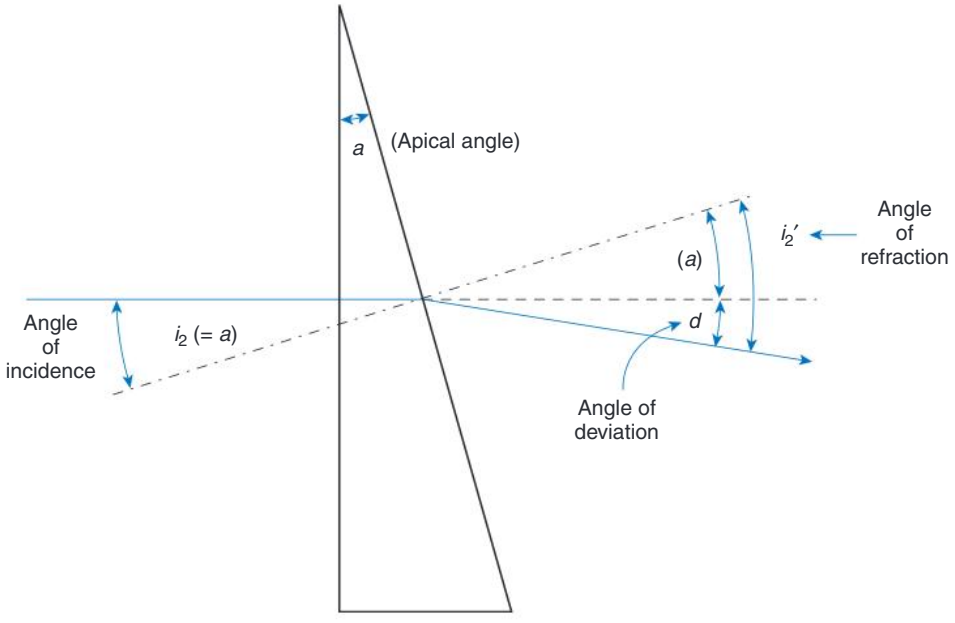


Figure 15.2 This prism is oriented with the first surface perpendicular to the incoming light ray. This means that the angle of incidence at the second surface (i_2) is equal to the apical angle of the prism. Note also that the angle of refraction (i_2') equals the apical angle (a) plus the angle of deviation (d).

For material with an index of 1.5, the calculation is even easier and reduces to:

$$d = a(n-1)$$
$$= (1.5-1)$$
$$= a(0.5)$$
$$d = \frac{a}{2}$$

In other words, when the lens is made from index 1.5 material (CR-39 plastic has an index of 1.498), then the angle of deviation is equal to half the apical angle.

Example 15.3

A prism with an index of refraction of 1.70 has an apical angle of 9 degrees. Using the thin prism approximation, what is the angle of deviation?

Solution

Because the prism index is far from 1.5, we cannot use the very simple approximation and just divide the apical angle by 2. Instead we use:

$$d = a(n-1)$$

In this case, by substituting, we get:

$$d = a(n-1)$$
$$= 9(1.7-1)$$
$$= 9(0.7)$$
$$= 6.3 \text{ degrees}$$

The angle of deviation is 6.3 degrees.

Example 15.4

A prism made from CR-39 plastic has an apical angle of 8 degrees. Using the thin prism approximation, what is the angle of deviation?

Solution

This is the same problem as given in Example 15.1. This time, however, we can use the most simplified form of the thin prism approximation since CR-39 plastic is so close to 1.5 index. Therefore,

$$d = \frac{a}{2}$$
$$= \frac{8}{2}$$
$$= 4 \text{ degrees}$$

Finding Apical Angle From Degrees of Deviation

It is possible to find the apical angle from degrees of deviation by transposing the same thin prism simplified equation of:

$$d = a(n-1)$$

that was described previously to:

$$a = \frac{d}{n-1}$$

Example 15.5

A prism made from 1.66 index material is shown to deviate light 6 degrees. What is its apical angle?

Solution

Using the equation:

$$a = \frac{d}{n-1}$$

we can substitute and find:

$$a = \frac{6}{1.66-1}$$
$$= \frac{6}{0.66}$$
$$= 9.09 \text{ degrees}$$

So, the apical angle of the prism is approximately 9.1 degrees.

The Prism Diopter (Δ)

The power of a prism could be quantified in terms of apical angle. The problem is that prism power would vary depending upon the refractive index of the prism. So, this does not work well.

A prism could also be quantified in terms of the angle of deviation in degrees that it produces. This is better because it is independent of index. However, angle of deviation is not as easy to work with for ophthalmic purposes.

A third way of quantifying prism power is to express it in terms of how far it displaces light when measured on a flat screen. In other words, how far was light displaced from the point it would otherwise have struck at a given distance from the prism had it not first been bent by the prism. This type of unit is called the *prism diopter* and is abbreviated by the Greek delta symbol (Δ). The prism diopter is an angular measure derived by using the tangent of the angle of deviation. The prism diopter is the unit of angular measure whose tangent is 0.01 or $\frac{1}{100}$.

Remember, in trigonometry, the tangent of an angle is the opposite over the adjacent.

$$\tan d = \frac{opp}{adj}$$

This is shown in Figure 15.3. This means that for a screen 100 cm away, if a prism displaces the image 1 cm, the prism has a power of 1 prism diopter. So, from the geometry of Figure 15.4, we see that:

$$\tan d = \frac{P}{100}$$

where P is the number of centimeters that the image is displaced at a distance of 100 cm (1 m). By definition, P will also be the number of prism diopters of prism displacement power.

Finding Prism Displacement for Any Distance

If prism displacement can be written as:

$$\tan d = \frac{P}{100}$$

we can also determine prism diopters if we know the amount of displacement of the ray for any given distance from the prism. If the

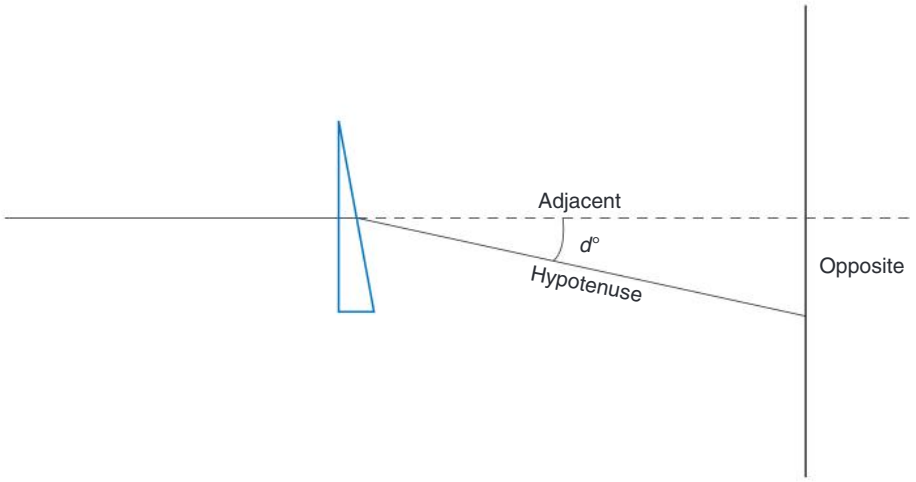


Figure 15.3 A trigonometric rationale for converting degrees of deviation to prism diopters.

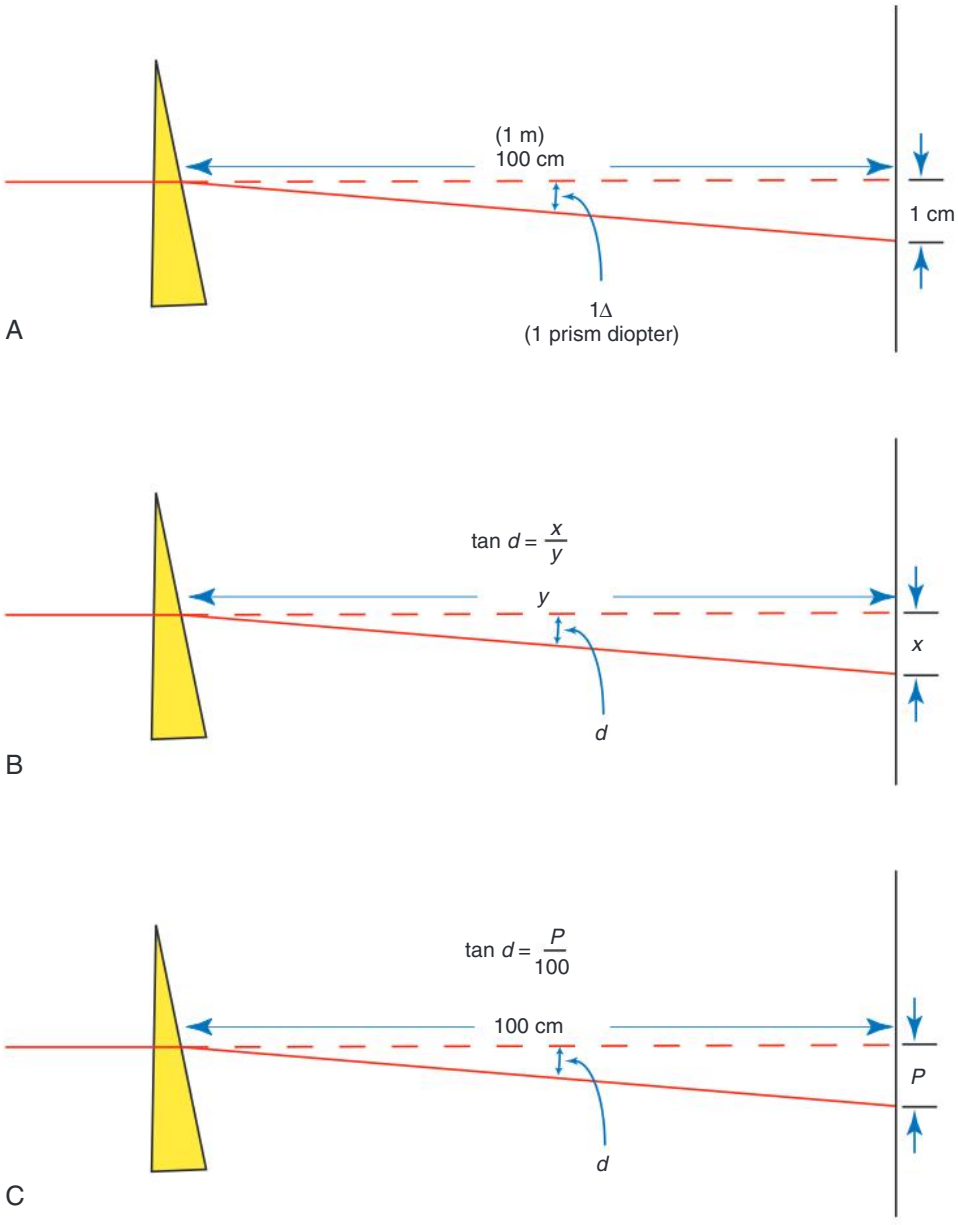


Figure 15.4 **A**. We see that, by definition, a prism having a power of 1 prism diopter (1Δ) will displace a ray 1 cm at a distance of 100 cm. **B**. We notice that the angle of deviation (d) caused by the prism and the amount of displacement (x) on a plane at a given distance (y) from the prism can be described by $\tan d = \frac{x}{y}$. **C**. Knowing what we see in **B,** we can relate prism diopters to the angle of deviation with the relationship: $\tan d = \frac{P}{100}$.

displacement is x units on a flat plane that is located y units from the prism, then:

$$\tan d = \frac{x}{y}$$

This means that:

$$\tan d = \frac{P}{100} = \frac{x}{y}$$

or

$$\frac{P}{100} = \frac{x}{y}$$

Notice that both x and y must be the same units of measure. If x is in centimeters, then y must also be in centimeters (see Figure 15.4, *B*).

Example 15.6

A prism displaces light at a lateral distance of 9 cm at a plane 300 cm from the prism. What is the power of the prism in prism diopters?

Solution

Using the equation:

$$\frac{P}{100} = \frac{x}{y}$$

and knowing that $x = 9$ cm and $y = 300$ cm, then:

$$\frac{P}{100} = \frac{9}{300}$$

$$P = \frac{(9)(100)}{300}$$

$$= 3\,\text{cm}$$

So, basically we used similar triangles to find that for a displacement of 3 cm at a distance of 100 cm, this prism has a power of 3Δ. This is because, by definition, a 3-cm ray displacement at a distance of 100 cm is 3 prism diopters (Δ).

If we were to use the equation:

$$\frac{P}{100} = \frac{x}{y}$$

and change the units of measure for the distance from the prism to the screen into meters, then we would have:

$$\frac{P}{1\,\text{m}} = \frac{x\,\text{centimeters}}{y\,\text{meters}}$$

or

$$P = \frac{x\,\text{centimeters}}{y\,\text{meters}}$$

Example 15.7

How much prism power does a prism have if it displaces a ray of light 5 cm from a position it would otherwise strike at a distance of 1 m from the prism?

Solution

If displacement (x) is 5 cm and "screen" distance is 1 m, then:

$$P = \frac{x\,\text{centimeters}}{y\,\text{meters}}$$

$$= \frac{5\,\text{cm}}{1\,\text{m}}$$

$$= 5\,\Delta$$

The answer is 5Δ.

Example 15.8

How much prism power does a prism have if it displaces a ray of light 5 cm from a position it would otherwise strike at a distance of 5 m from the prism?

Solution

The only change in this example problem compared to Example 15.8 is the "screen" distance, which increases to 5 m. So, if:

$$P = \frac{x\,\text{centimeters}}{y\,\text{meters}}$$

then

$$P = \frac{5\,\text{cm}}{5\,\text{m}}$$

$$= 1\,\Delta$$

Conversion from Degrees of Deviation to Prism Diopters

It is possible to convert back and forth from degrees of deviation to prism diopters using trigonometric functions as described earlier and as shown in the equation:

$$\tan d = \frac{P}{100}$$

Example 15.9

How many prism diopters are produced for each degree of deviation?

Solution

For 1 degree of deviation, we begin by finding the tangent of 1 degree.

$$\tan 1 = 0.0175$$

using:

$$\tan d = \frac{P}{100}$$

For each 1 degree of deviation,

$$0.0175 = \frac{P}{100}$$

So,

$$P = (0.0175)(100)$$

$$= 1.75\,\Delta$$

Therefore, each degree of deviation produces 1.75 prism diopters.

Example 15.10

How many degrees of deviation are produced by 1Δ?

Solution

This time we are going the other way.

$$\tan d = \frac{P}{100}$$
$$\tan d = \frac{1}{100}$$
$$\tan d = 0.01$$

Finding the inverse tan of 0.01 gives a value of:

$$d = 0.573 \text{ degrees}$$

So, for small amounts of deviation, one can simply remember that 1 degree = 1.75Δ, and 1Δ = 0.57 degrees. (Note: At this point, it should be mentioned that some manufacturing opticians refer to prism diopters by using the term *degrees of prism*. Although sometimes used in the trade and understood to be the same thing as a prism diopter, this use of the term *degrees* is technically inaccurate and must not be confused with either degrees of deviation or apical angle as expressed in degrees.)

The Prism Centrad (∇)

A seldom-used method of quantifying prism deviation is the centrad (∇). A centrad is similar to a prism diopter in that a ray is displaced 1 cm at a distance of 1 m from the prism. The difference between the two is that a prism diopter is measured on a flat plane 1 m away, whereas the displacement of a centrad is measured on the arc of a circle having a 1-m radius (Figure 15.5). The centrad is thus a more consistent unit of measurement, but it is not used clinically. For small angles of prism deviation, the centrad and the prism diopter are nearly equal. However, as the amount of prismatic deviation increases, the two become increasingly different. Each centrad is slightly larger than a prism diopter, because each radian is slightly larger than a degree.

Image Displacement

If a prism is placed before an eye, the deviated ray enters the eye. The eye itself has no way of knowing that the ray has been deviated. It simply appears to be coming from a different direction. Since this ray comes from a specific object, the object itself appears to be displaced. Since there is no actual displacement, what the eye sees is a displaced image of that object. The phenomenon is referred to as image displacement and is shown in Figure 15.6.

The amount of image displacement is predictable from the power of the prism and can be expressed in prism diopters. This corresponds exactly to the previous definition. As seen in Figure 15.7, if a ray of light is displaced 1 cm at a distance of 1 m from the prism, the image of an object in front of the prism will be correspondingly displaced 1 cm for each meter the object is from the prism.

Direction of Image Displacement

As previously seen, a single ray of light is deviated in the direction of the prism's base. From the point of view of an observer holding the prism before his or her eye, the prism causes the image of a viewed object to be

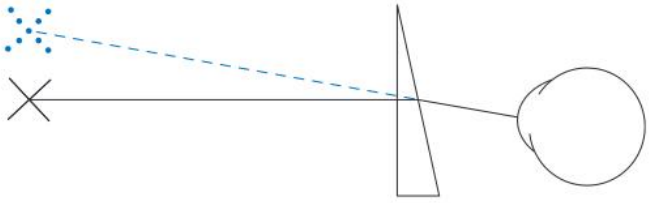


Figure 15.6 When looking through a prism, the image of an object appears to be displaced from its actual location.

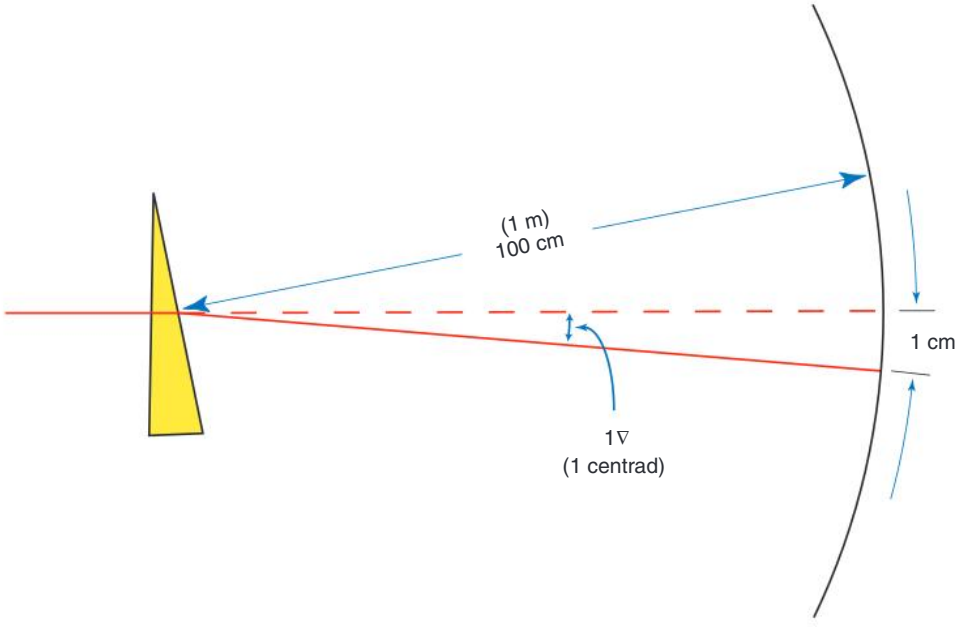


Figure 15.5 One (1) centrad equals one hundredth part of a radian. The one hundredth part is measured on the circular arc. If the radius equals 100 cm, then 1 centrad (∇) is 1 cm measured on the curved arc.

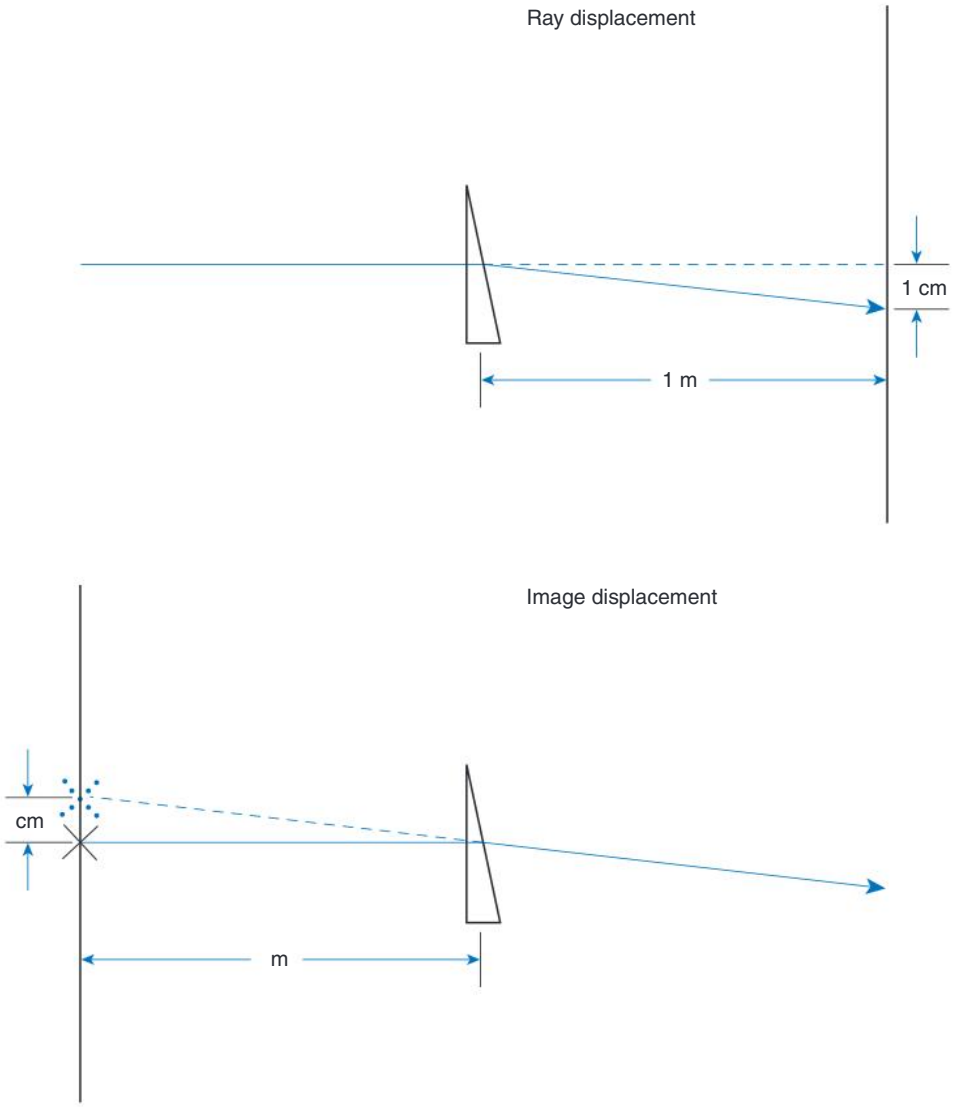


Figure 15.7 How prism diopters correspond for both displacement of rays from an object and displacement of images.

displaced in the direction of the apex of the prism. To remember this easily, think of the prism as being an arrow with its apex pointing in the direction of the displaced image. "*The eye turns in the direction the prism points.*"

Practical Application

Prism is used in a spectacle lens prescription to either cause or allow the eye to turn from the normal straight-ahead viewing direction. If one eye turns upward, a prism may be placed with its base down before that eye. This causes an object to appear as if it is farther up than it actually is. When this is done, the image the eye sees will correspond to the position where the deviant eye is looking so that both eyes may more easily work together as a team. In this simplified example, the direction of prism orientation would depend on which way the eye tended to point.

How to Specify Prism Base Direction

There is more than one way of specifying prism base direction. Lens prescribers tend to use one method because it fits in more with how they measure the amount of prism needed. The optical surfacing laboratory uses another method because prism can only be ground in a certain manner.

The Prescriber's Method

The person prescribing prism generally uses the wearer's face to reference the prism direction. The top and bottom of the wearer's face and the nose or sides of the head are used to specify base direction. If the prism is "right side up," with the base downward and the apex pointing upward, the prism is said to be a base-down prism. If it is "upside down," the prism is said to be base up (Figure 15.8).

If the prism is on its side, so to speak, the base of the prism will be oriented either in the direction of the nose or outward away from the nose. Prism oriented with its base toward the nose is said to be base in (Figure 15.9). Prism turned with its base away from the nose is referred to as being base out (Figure 15.10). This is perfectly adequate for those doing the prescribing since vertical and horizontal prism elements are considered separately. If both horizontal and vertical prism corrections are required, then two prism elements are prescribed.

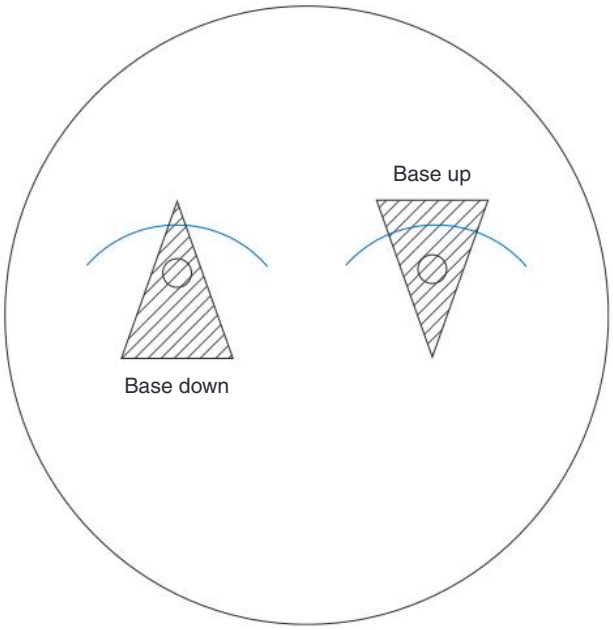


Figure 15.8 It is not necessary to know which eye a prism is on to be certain what "base down" or "base up" means. (However, base down before the right eye has the same effect for the wearer as base up before the left. They are *not* opposite effects.)

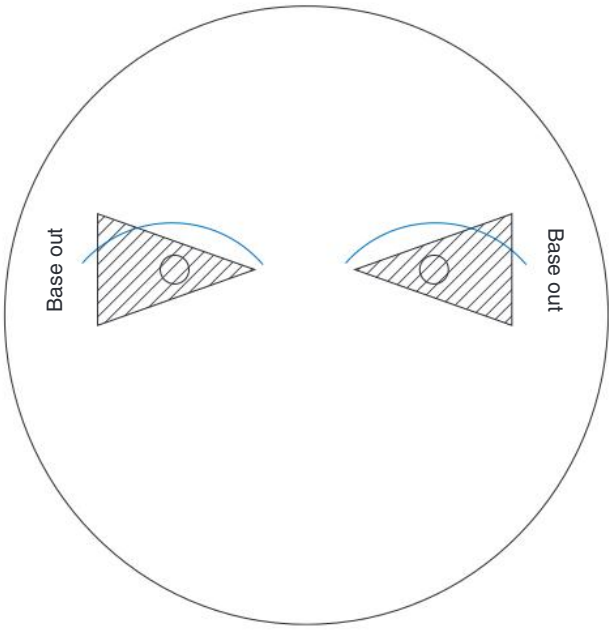


Figure 15.10 Even though the prism bases go in opposite directions, both are classified as "base out." It is not possible to know exactly which way a base-out prism is oriented until a right or left eye is specified.

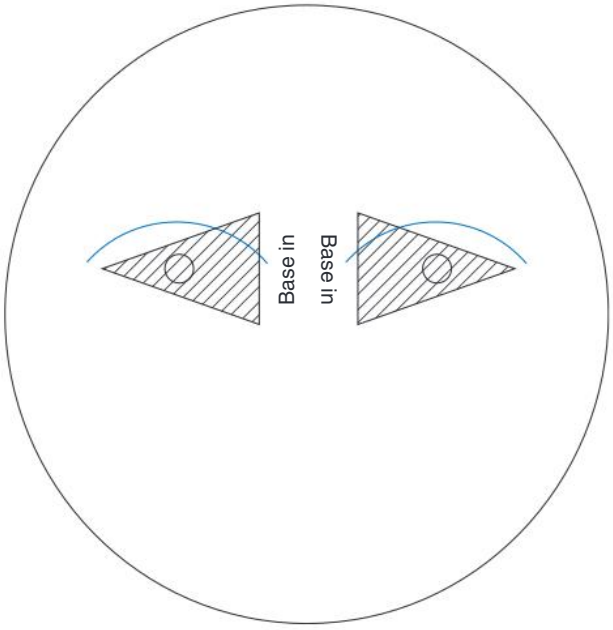


Figure 15.9 When horizontally oriented prism is prescribed for both eyes, it is almost always either base in for both eyes or base out for both eyes. Base-in prisms on both right and left eyes do not cancel each other but rather augment the desired effect.

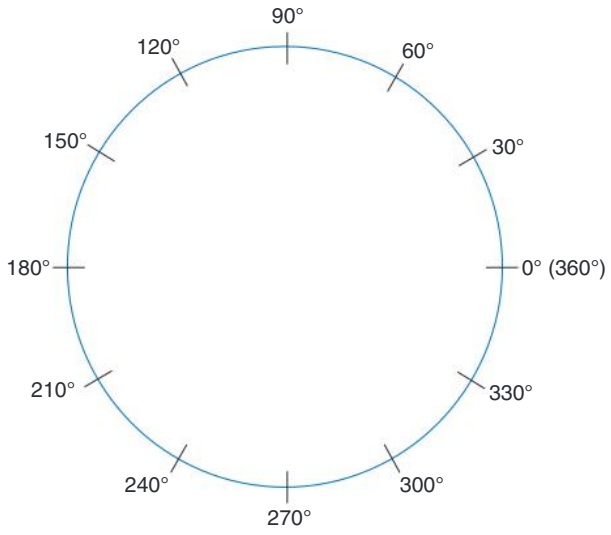


Figure 15.11 The degree system for prism is close to that used for specifying cylinder axis.

Unfortunately, this is somewhat limiting for the optical surfacing laboratory. First of all, if base-in or base-out prism is prescribed, it depends on which eye is being referenced as to which direction the base of the prism actually faces. For the right eye, base-in prism means that the base goes to the right, but for the left eye, a base-in prism means that the base goes to the left.

A 360-Degree Laboratory Reference System

Although the prescriber's method of specifying prism is well suited for those examining eyes and those dispensing eyewear, it is not adequate for the optical laboratory.

The 360-degree laboratory reference system uses the standard method of specifying direction in degrees, as shown in Figure 15.11. When a lens is viewed from the front (convex side facing the observer), the base direction is specified as follows: If the base is to the right, it is specified as base 0 degrees. If the base is oriented in an upward direction, it is base 90 degrees. To the left is base 180 degrees, and straight down is base 270 degrees.

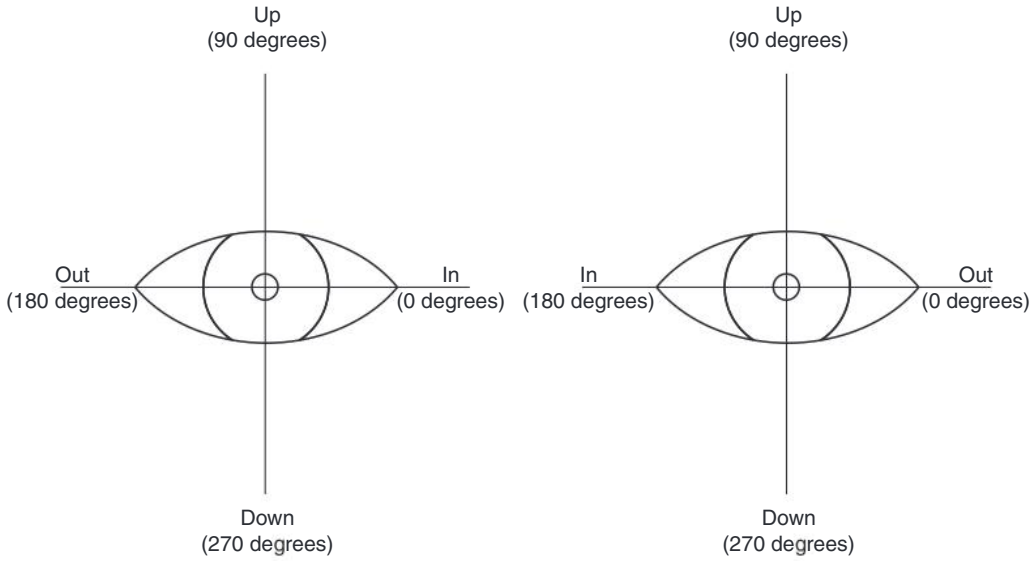


Figure 15.12 Prism base orientation is specified by eye as up, down, in, or out. Base orientations may also be specified in degrees, although prescriptions for an individual's glasses are seldom written as such.

The prescriber's method uses a rectangular coordinate system of horizontal and vertical measures. The laboratory method uses a polar coordinate system of degrees.

Converting the Prescriber's Method to the Laboratory System

Suppose a prescription calls for 2Δ of base-down prism. What is that in the 360-degree laboratory reference system?

Base-down prism is below the 180-degree line. Therefore, it must be greater than 180 degrees. Since there are only four directions in the prescriber's method, it must be 0, 90, 180, or 270 degrees. The 270-degree direction is straight down. Therefore, 2Δ of base-down prism corresponds to base 270.

When there is only one prism element to the prescription lens, there is little difficulty in converting (Figure 15.12). However, if there are two elements, one horizontal and one vertical, then the conversion may result in any one of the full 360 degrees.

Converting From the Prescriber's Method When Two Prism Elements Are Involved

Sometimes a prescription calls for two amounts of prism in two different directions, both on the same eye. When lenses are ground, it is not possible to work with two prisms. Instead the two prisms are combined into one new prism. Fortunately, the end result is the same.

Using one prism instead of two is like taking a shortcut across a field. Instead of walking 2 miles west and 2 miles north, it is possible to walk 2.83 miles northwest and arrive at exactly the same location. (Those familiar with geometry will recognize this as simply the sum of two vectors. To review this concept, see Chapter 11.) Therefore, instead of grinding 2 diopters of base-out prism for the right eye (prism at 180 degrees) and 2 diopters of base-up prism (prism at base 90 degrees), it is possible to grind 2.83 diopters of prism halfway between (which in this case corresponds to base 135 degrees).

Although this may seem difficult to visualize initially, anyone who is accustomed to using a lensmeter has already been using this system for some time. The lensmeter uses a system of rings inside the instrument to indicate the amount of prism being measured. If the lensmeter is focused, the lines on the target cross at the location of the optical center of the lens. Normally the lens is moved until the target lines are superimposed on the center of the lensmeter reticle as

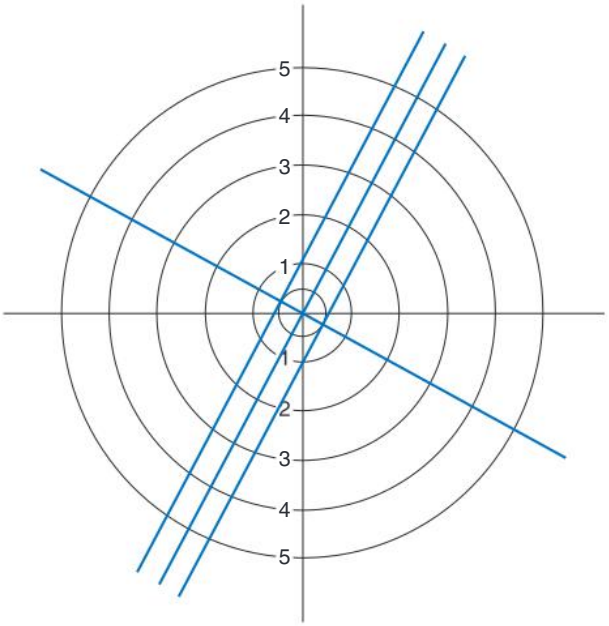


Figure 15.13 When the target is centered in a lensmeter, the optical center of the lens has been located.

in Figure 15.13. If the target lines are not centered, the place on the lens where the lensmeter is measuring creates a prismatic effect. The amount of prism is indicated by the location of the intersection of the target lines.

For example, if the target lines intersect on the reticle ring marked "1," the lens shows 1 diopter of prism. If the target lines are on the "1" reticle ring exactly above the center of the reticle as shown in Figure 15.14, the prism direction is base up. As would be expected, a base-in or base-out effect will be seen to the left or right, depending on which lens is being measured (Figure 15.15).

If a lens is placed in the lensmeter and the intersection of the target lines occurs at a location other than on the vertical or horizontal reticle line, then both vertical and horizontal prism are being manifested. The amount of each is found by drawing imaginary lines from the target

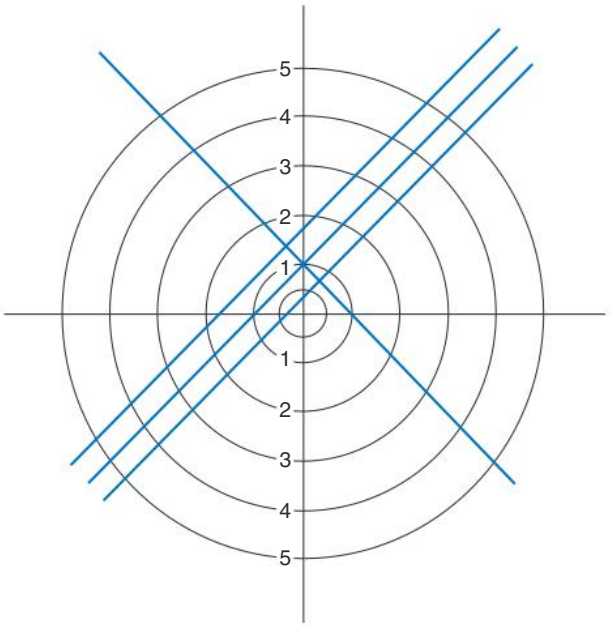


Figure 15.14 If a lens shows this in the lensmeter, there is 1 prism diopter of base-up prism at the point on the lens being looked through. This is true regardless of whether it is a left or a right lens.

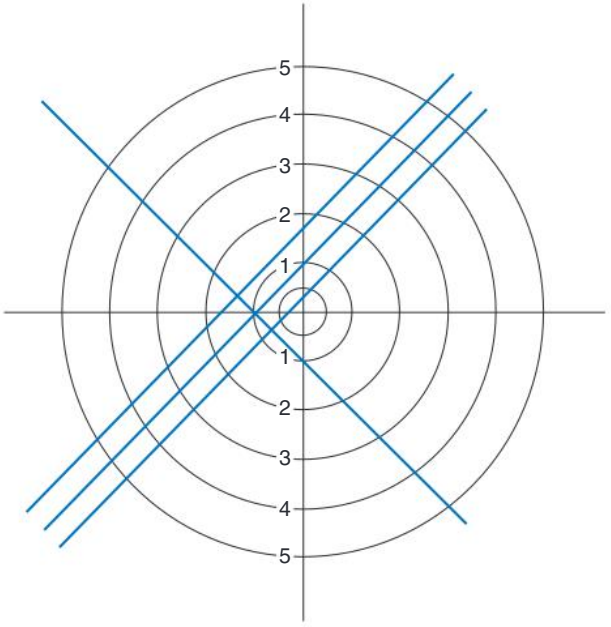


Figure 15.15 For this lens, the amount of prism is 1Δ. However, since we do not know whether the lens is for the left or right eye, we do not know if the prism is base in or base out. If the lens is intended for the right eye, the base direction is base out.

center to the horizontal and vertical lines of the reticle. In Figure 15.16, if the lens is a right lens, the amount of prism manifested is 2Δ base in and 1Δ base up. However, the location of the center of the target really shows only one prism. By looking at the figure, it can be seen that the amount of prism is really about 2.25Δ. The base direction is approximately 27 degrees. (Most lensmeters have a degree scale within the reticle that can be used to measure the angle.) We now have a simple system for converting the prescriber's method to the laboratory reference system of recording prism.

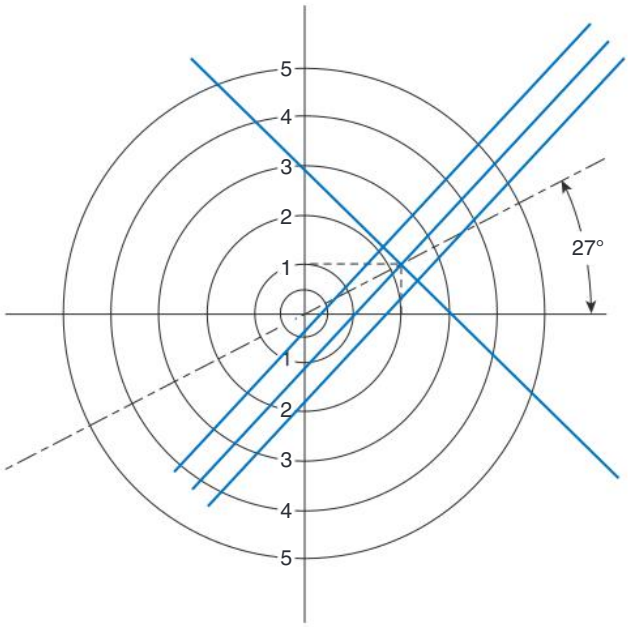


Figure 15.16 Assuming that this lens is for the right eye, the prismatic effect shown is 2Δ base in and 1Δ base up. The base direction of the resultant prism is 27 degrees. It should be noted that the tilt of the triple and single target lines do *not* tell base direction. Within the eyepiece is a hairline that is turned until it crosses the center of the target. This hairline indicates the correct number of degrees. (The interior degree scale is not shown.)

Here are some typical problems for converting the prescriber's method to the laboratory method.

Example 15.11

If a right lens calls for 1 diopter of base-in prism, what is that in degrees?

Solution

When visualizing prism direction, the lens is always thought of as if the lens (or glasses) has the convex surface facing you (in other words, looking at the glasses as they would appear when being worn by someone else). Therefore, for a right lens, a base in direction is toward the right. On the prism chart this is in the 0-degree direction. Thus, the answer is 1Δ base zero.

Example 15.12

What if the prescription for the *left* eye in Example 15.11 *also* called for 1 diopter of prism base in? Expressed in degrees, what would that base direction be?

Solution

When viewing a left lens from the front, the nose will be to the left. Therefore, the base direction is to the left, causing the base to be now in the 180-degree direction.

The answer is 1Δ base 180. So now, even though the prescriber's method indicates base-in prism for both the right and left lenses, the right-eye prism is base zero, and the left-eye prism is base 180.

Prism Base Direction for Paired Lenses

Prism is normally prescribed to compensate for difficulty the eyes have in working together (i.e., for the purposes of addressing a binocular vision problem). Because eyes work as a team, prism placed in front of one eye affects both eyes. Therefore, the full prism correction may be placed before one eye, or the correction may be divided between the two eyes. Dividing the prism may be done as an even split or by placing an unequal portion before one eye and the remainder before the other.

Splitting Horizontal Prism

Very often, horizontal prism is split evenly in front of both eyes. Both prisms will be base in, or both will be base out.

It is perfectly legitimate to split prism unevenly. For example, instead of splitting prism as:

R: 2Δ base out
L: 2Δ base out

the prescriber may cause the same effect binocularly with

R: 3Δ base out
L: 1Δ base out

or even

R: 0 prism
L: 4Δ base out

The net effect will be the same. One reason prism may be split unevenly may be because of eye dominance. In other instances, the choice of how to split prism may be made in an effort to either improve the cosmetic appearance of the lenses or equalize lens thicknesses.

Base-out prism in front of the right eye gives the same optical effect as base-out prism in front of the left eye. Base-in prism in front of the right eye gives the same optical effect as base-in prism in front of the left eye.

Splitting Vertical Prism

Vertical prism may also be split evenly or unevenly before the two eyes. An example of prism split evenly would be:

R: 2Δ base up
L: 2Δ base down

For example, the prescriber may cause the same effect binocularly with:

R: 3Δ base up
L: 1Δ base down

or

R: 0 prism
L: 4Δ base down

With vertical prism, base up in front of one eye creates the same effect as prism base down in front of the other eye.

This concept is more easily understood by remembering that a prism allows the eye to turn in the direction of the prism apex. Therefore, if the right eye turns up, a base-down prism before the right eye will allow the eye to turn upward (in the direction the prism apex points) and should help in preventing eyestrain or double vision.

Here is a diagram of how prism in one eye equates to prism in the other when considering the two eyes as a pair working together binocularly.

Right eye		Left eye
Base out		Base out
Base in	is the same as	Base in
Base up		Base down
Base down		Base up

COMPOUNDING AND RESOLVING PRISM

As seen earlier, a prescription may require both horizontal and vertical prism in the same lens. In the manufacturing process, one simple prism may be calculated such that it produces exactly the same effect as the two specified prisms combined would have. When two prisms are combined in power and base orientation to form one prism that is the equivalent of both, the process is known as *compounding prism.*

The reverse of compounding prism is the process of taking a prism whose base orientation is oblique and expressing it as two prisms oriented perpendicularly to one another. The process of expressing a single oblique prism as two perpendicular components is known as *resolving prism.*

When using a lensmeter to analyze a prescription pair of glasses containing both horizontal and vertical components, the two components appear as one compounded prism with the base oriented obliquely. This prism may be resolved into horizontal and vertical components. This may be done easily when the compounding and resolving processes are understood.

Compounding

Compounding of two prisms into one is done by exactly the same process used for obtaining the sum of two vectors (see Chapter 11). The two prisms are drawn to scale as vectors, the unit length of each

Example 15.13

A prescription for the right eye calls for 3Δ base in and 2Δ base up. What compounded prism must be ground onto the lens surface to arrive at the desired prescription?

Solution

The prisms are drawn to scale as shown in Figure 15.17, *A*. A parallelogram is completed (see Figure 15.17, *B*), and the resultant prism is drawn (see Figure 15.17, *C*). This prism is measured and found to be 3.6Δ. The prism base orientation is measured using a protractor and is found to be 34 degrees. Therefore, the resultant compounded prism is 3.6Δ base at 34 degrees.

This problem also may be solved using geometry and trigonometry. The horizontal prism component is designated *H*, the vertical component *V*, and the resultant prism *R*. The new base orientation of the resultant prism is θ. Because this graphic construction contains a right triangle, the value of the resultant is found using the Pythagorean theorem.

$$R^2 = V^2 + H^2$$

$$R = \sqrt{V^2 + H^2}$$

Since $V = 2$ and $H = 3$,

$$R = \sqrt{2^2 + 3^2}$$

$$= \sqrt{13}$$

$$R = 3.61\,\Delta$$

The base orientation is found from:

$$\tan\theta = \frac{V}{H}$$

because the side opposite angle θ is the vertical component, and the side adjacent is the horizontal component.

By using a calculator, the function inverse tan ($\tan^{-1}$) allows the angle θ to be found as 33.69 degrees.

Therefore, the resultant prism is 3.61Δ base at 33.69 degrees.

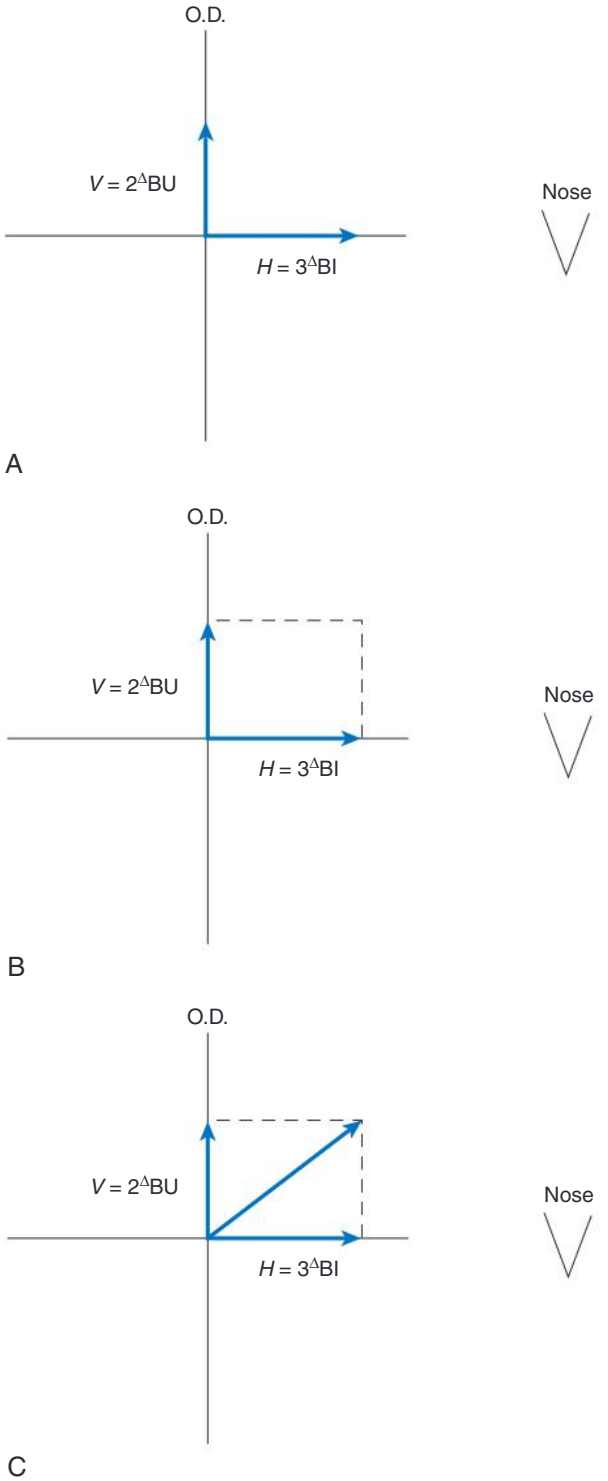


Figure 15.17 A. Compounding two prisms into one using a graphic method begins by entering two vectors on the axes of a Cartesian coordinate system. **B**. From the two-prism vector representations, a parallelogram is completed. **C**. The compounded prism that results is the diagonal of the parallelogram beginning from the origin. *BI*, base in; *BU*, base up; O.D., right eye.

corresponding to the units of prism power. The arrow points in the direction of prism base orientation. The tangent function and the Pythagorean theorem are the mathematical tools to compound prism.

Resolving

Reversing the previously described process resolves one oblique prism into horizontal and vertical components. First, the oblique prism is drawn to scale as a vector and oriented so that it points in the prescribed base direction. Horizontal and vertical lines are drawn from the tip of the arrow to the 90-degree and 180-degree axis line (*x*- and *y*-axes of the Cartesian coordinate system). The positions of intersection with the *x*- and *y*-axes mark the power of the horizontal and vertical prism resolved from the original prism. The sine and cosine functions are the mathematical tools to resolve prism.

Example 15.14

A wearer's right lens is placed in a lensmeter and prism found. That prism reads 2.00Δ base at 30 degrees. What horizontal and vertical prism values does this prove to be?

Solution

This prism is drawn on a coordinate system as shown in Figure 15.18. Horizontal and vertical lines are dropped from the tip of the vector to the *x*- and *y*-axes, and the distance from zero is measured. The vertical component measures 1.00Δ base up. The horizontal component measures 1.70Δ base in. (If this were the left lens, the base direction would be away from the nose and would be read as base out.)

In the example given, the target of the lensmeter, representing the spherical and cylindrical powers, will be displaced from its center position to the same degree and in the same direction as the resultant arrow in the graphic method would be (Figure 15.19). By mentally extending lines from the lensmeter target center until they intersect the *x*- and *y*-axes, the power of the prisms are determined.

The resolving of prism may also be calculated trigonometrically using equations derived from the geometry of the figure. These are:

$$V = P \sin\theta$$
$$H = P \cos\theta$$

where P is the power of the oblique prism and θ the base orientation. Using the previous problem,

$$V = 2.00 \sin 30$$
$$= 2.00 \times 0.5$$
$$= 1.00$$

So, as before, the vertical component is found to be 1.00Δ. For the horizontal component,

$$H = 2.00 \cos 30$$
$$= 2.00 \times 0.86603$$
$$= 1.73\Delta$$

The horizontal component has a power of 1.73Δ. Base direction is evident from the orientations of the original prism.

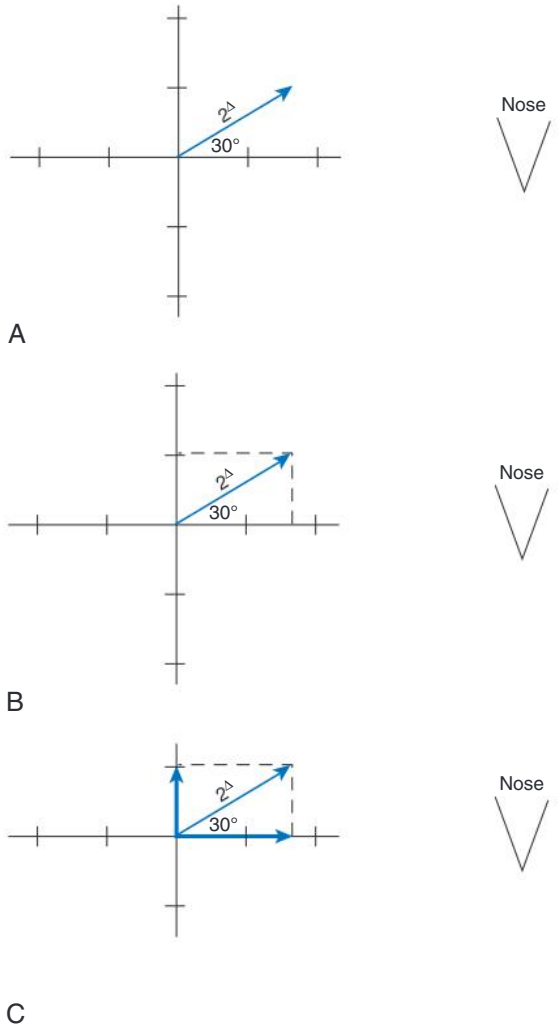


Figure 15.18 **A**, Resolving a single prism into its equivalent horizontal and vertical components begins by placing a vector on a graph such that it is representative of the prism power in length and represents base orientation in degrees. **B**, Individual component lengths are found by dropping perpendiculars to the *x*- and *y*-axes. **C**, In essence, by dropping perpendiculars, a parallelogram has been constructed in reverse, using its diagonal. The horizontal and vertical components are easily measured from the lengths of the two sides.

Combining Two Obliquely Crossed Prisms

At first glance, the problem of combining two oblique prisms into one single prism seems difficult. However, there are no new concepts here. In general terms, this can be done as follows:

1. Take each oblique prism and resolve it into its horizontal and vertical components.
2. Add the horizontal components from the two prisms together into one.
3. Add the vertical components from the two prisms together into one.
4. Compound the resultant vertical and horizontal components into a new single prism.

Here is an example:

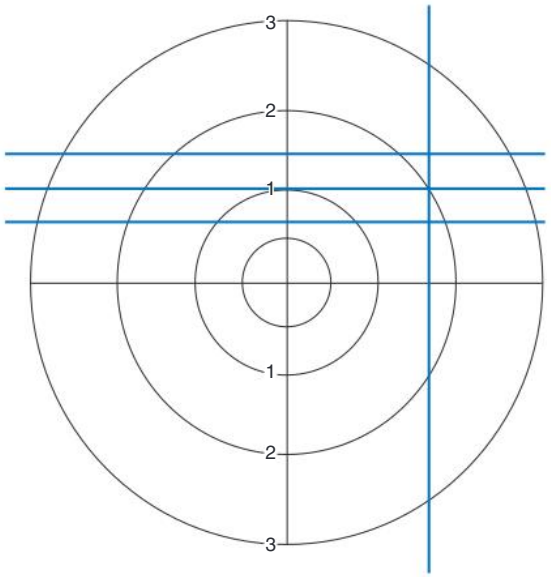


Figure 15.19 The most familiar example of resolving prism occurs daily when using a lensmeter. The intersection of the sphere and cylinder lines gives the location of the prism base. Perpendiculars from this intersection point, down and across to the *x*-, *y*-coordinate positions on the inner scale indicate the amounts of the horizontal and vertical prism components. (Because sphere and cylinder target lines may be turned in directions other than 90- or 180-degree positions during verification of a spherocylinder lens, simply following these lines to their intersection with the *x*- and *y*-axes will not always give the correct answer as might be initially imagined from the simplified construction of the figure.)

Example 15.15

Combine these two oblique prisms together into one prism:

2.83Δ base 135
5.00Δ base 037

Solution

Draw these two prisms as vectors to help in visualizing the problem. This is done in Figure 15.20, *A*. Take the 2.82Δ base 135 prism and find the horizontal and vertical components. By plotting this out as shown in Figure 15.20, *B1*, we can see that the vertical component is:

$$\begin{aligned} V &= P \sin\theta \\ &= 2.83 \sin 45 \\ &= (2.83)(0.707) \\ V &= 2.00\Delta \end{aligned}$$

The base direction is at 90 degrees. The vertical component is 2.00Δ base 090.

Because the triangle is a right triangle with two 45-degree angles, we know the horizontal component will also be 2.00Δ, and the base direction will be to the left or 180 (i.e., 2.00Δ base 180).

The second oblique prism of 5Δ base 037 is drawn as shown in Figure 15.20, *B2*. The vertical component is:

$$\begin{aligned} V &= P \sin\theta \\ &= 5 \sin 37 \\ &= 5(0.60) \\ &= 3.00\Delta \end{aligned}$$

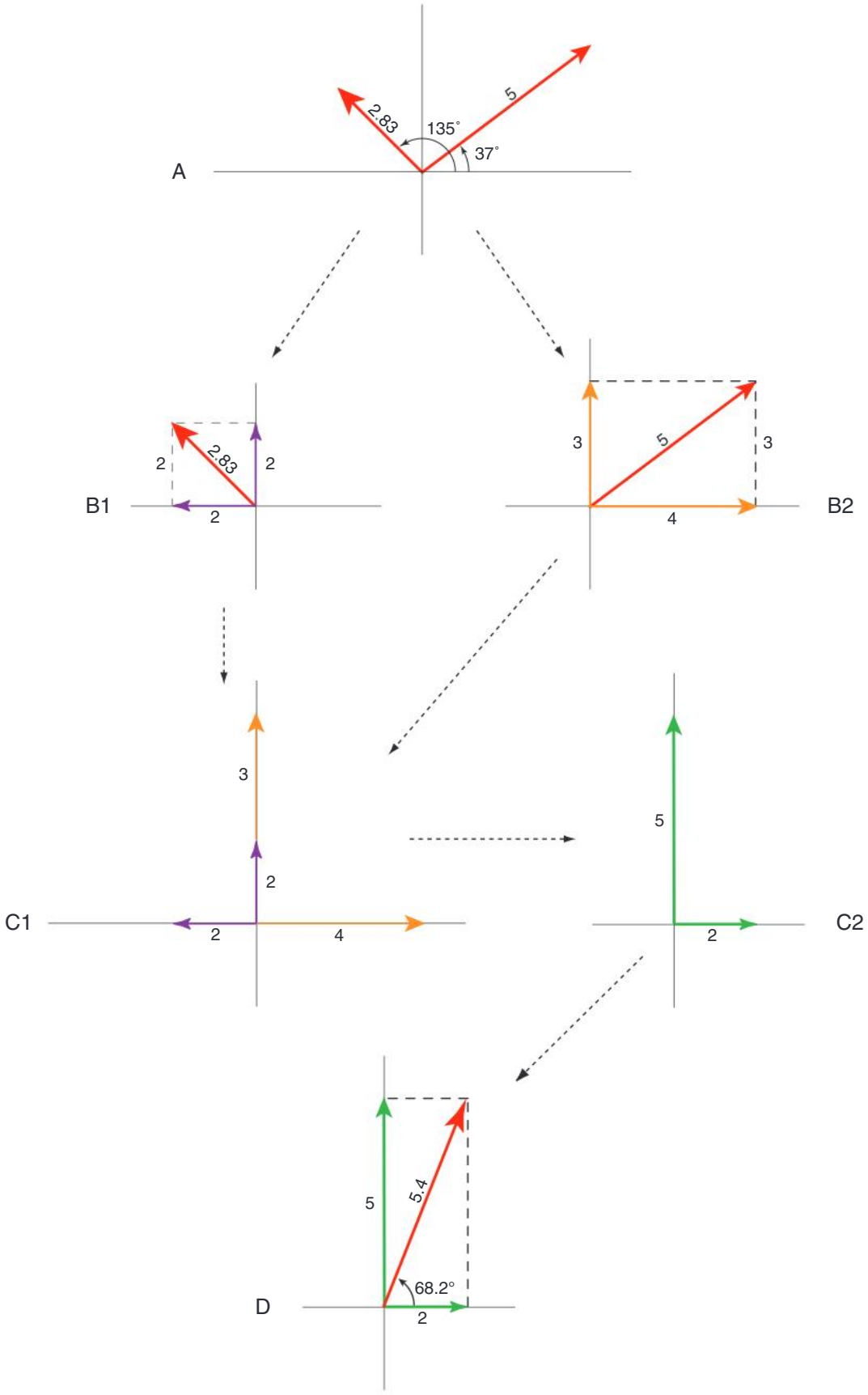


Figure 15.20 **A**, When combining two obliquely crossed prisms, consider each prism independently and split each prism into horizontal and vertical components. **B1**, A 2.83Δ base 135 prism becomes 2Δ base left (base 180) and 2Δ base up (base 090). **B2**, A 5Δ base 037 prism becomes 4Δ base right (base zero) and 3Δ base up (base 090). **C**, When horizontal and vertical components of the two obliquely crossed prisms are added, they become 2Δ base right (base zero) and 5Δ base up (base 090). **D**, When 2Δ base right (base zero) and 5Δ base up (base 090) are combined, they become 5.4Δ base at 68.2 degrees.

The base direction is base up or base at 90 degrees (i.e., 3.00Δ base 090). The horizontal component is:

$$\begin{aligned} H &= P\cos\theta \\ &= P\cos 37 \\ &= 5(0.799) \\ &= 4.00\Delta \end{aligned}$$

The base direction is right or at base zero degrees (i.e., 4.00Δ base 000).

Now, we can add the two horizontal and the two vertical components as shown in Figure 15.20, *C*.

$$2.00\Delta \text{ Base } 090 + 3.00\Delta \text{ Base } 090 = 5.00\Delta \text{ Base } 090$$

$$2.00\Delta \text{ Base } 180 + 4.00\Delta \text{ Base } 000 = 2.00\Delta \text{ Base } 000$$

If we only needed horizontal and vertical components, we would be finished. If this was a right eye, the answer would be 5.00Δ base up and 2.00Δ base in. If it was a left eye, it would be 5.00Δ base up and 2.00Δ base out.

However, to complete the problem so that the answer is a single prism, we need to find the vector sum of both prisms. This is shown in Figure 15.20, *D*, and is calculated as follows:

$$\begin{aligned} P^2 &= V^2 + H^2 \\ P &= \sqrt{5^2 + 2^2} \\ &= \sqrt{25 + 4} \\ &= \sqrt{29} \\ P &= 5.4\Delta \end{aligned}$$

The base direction is found this way:

$$\tan\theta = \frac{V}{H}$$

$$\tan\theta = \frac{5}{2} = 2.5$$

$$\theta = 68.2 \text{ degrees}$$

So, the final prism amount is 5.4Δ base at 68.2 degrees. Incidentally, it would have been possible to graph the two prism vectors to scale and find the resultant prism vector of 5.4Δ base 68.2 by measuring it. This is shown in Figure 15.21.

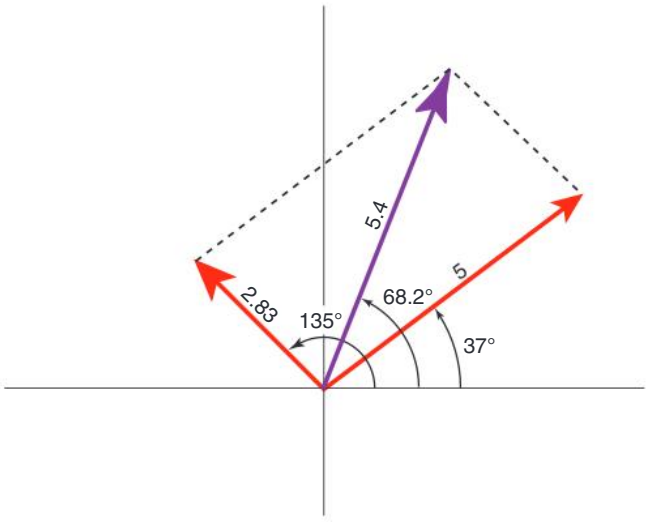


Figure 15.21 When drawn to scale, obliquely crossed prisms can be combined graphically and the resultant prism amount and base direction measured directly without calculating the result using trigonometry as was shown in the previous figures.

ROTARY PRISMS

There is an application of obliquely crossed prisms that is used on a regular basis in ophthalmic practice. That application is called a *rotary*, or *Risley*, *prism*. A rotary prism is a combination of two prisms. These prisms are placed one on top of the other. Initially, their base directions are exactly identical, but as the prisms are rotated, their bases move by equal extents in opposite rotational directions.

For example, suppose two prisms of 10Δ each are placed on top of one another base to base. The total prismatic effect is 20Δ (Figure 15.22, *A*). But if they are placed base to apex, then their total prismatic effect is zero (see Figure 15.22, *B*).

Now suppose we begin with both 10Δ prisms base down. Together, they total 20Δ base down. Next, we rotate one prism base 37 degrees clockwise and the other base 37 degrees counterclockwise. Now what prismatic effect is being manifested?

We plot each prism in vertical and horizontal components as seen in Figure 15.23. This shows that the horizontal components are equal and opposite. They cancel out. The vertical components are both 8Δ base down, which, when added, equal 16Δ base down.

As the prisms continue to be rotated in opposite directions, the horizontal components increase equally and continue to cancel out, and the vertical components decrease. This continues until both prisms are fully horizontal—one base left, the other base right. Now there is neither horizontal nor vertical prism. The prismatic effect is zero. If the two prisms continue to be rotated past the horizontal, base-up vertical prism begins to increase and continues to increase until both prisms are fully base up. As these prisms were being rotated, there was never anything but vertical prism being manifested.

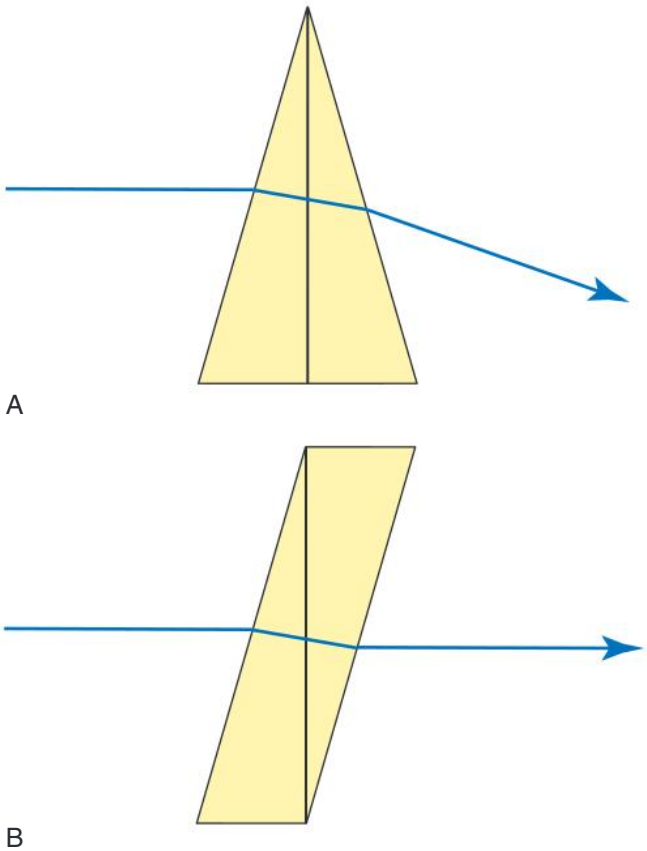


Figure 15.22 **A**, A Risley, or rotary, prism is really two prisms, one on top of the other. When these equally powered prisms are placed base to base, their combined prism amount is at a maximum. **B**, When a Risley, or rotary, prism has the two prism elements base to apex, the resultant amount is zero.

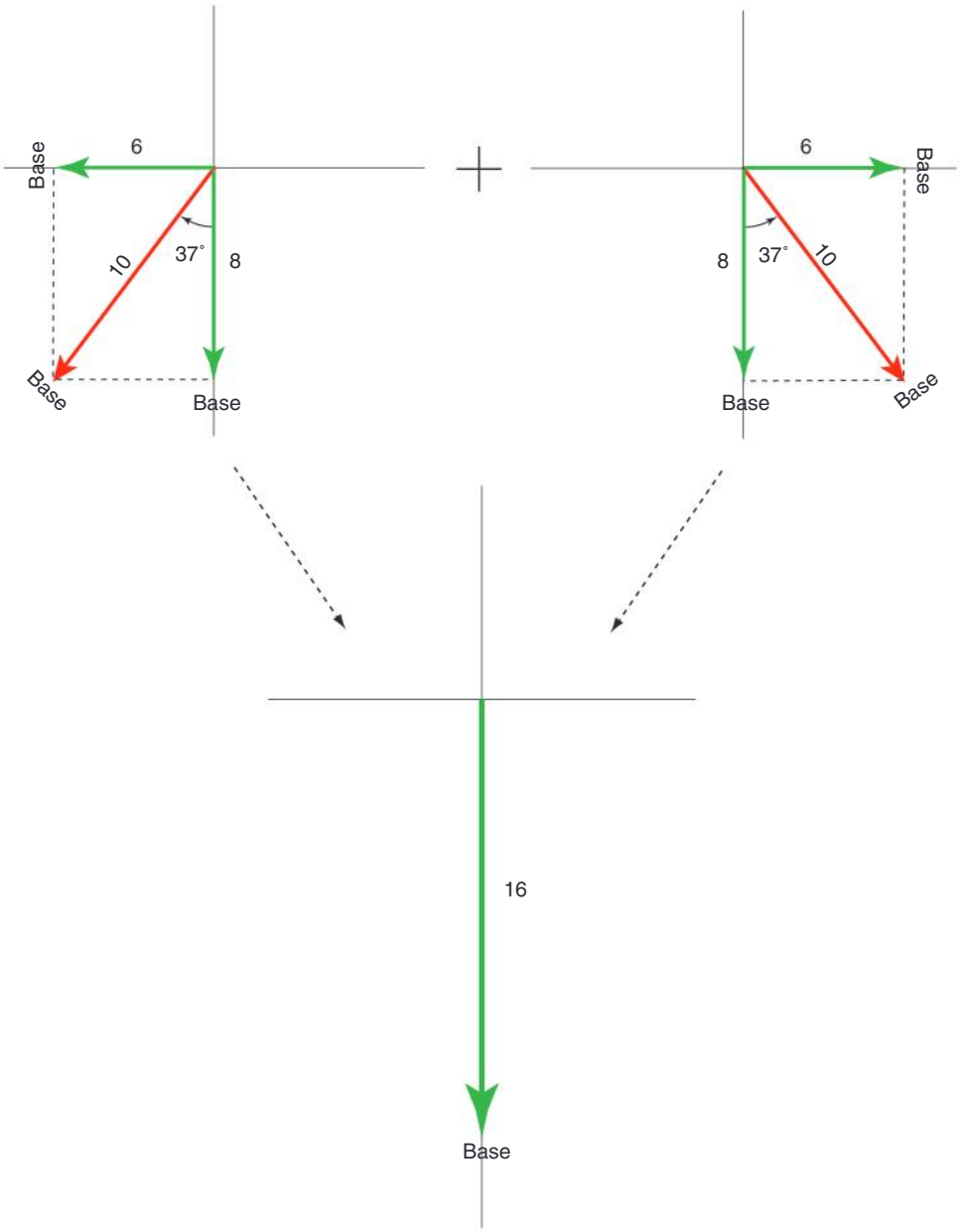


Figure 15.23 For this Risley prism combination, the base direction for both 10Δ prism elements started out as base down and totaled 20Δ base down. Next, they were rotated in opposite directions, one clockwise and the other counterclockwise. This causes their equal and opposite horizontal components to cancel each other out. Their vertical components are additive. Here they add up to 16Δ base down.

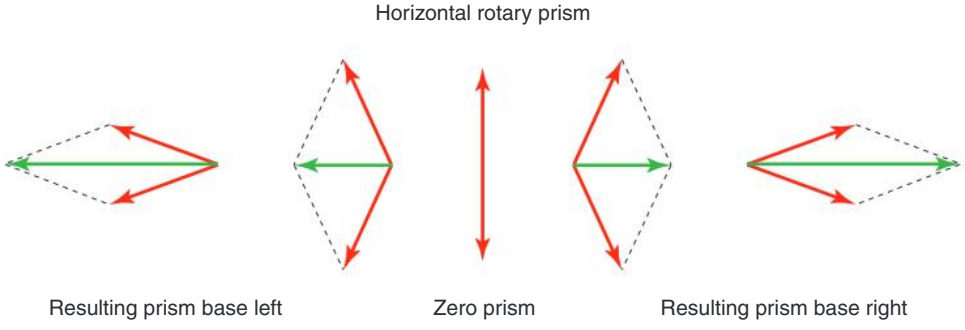


Figure 15.24 Here, the combining actions of the two prism components in a horizontally oriented Risley, or rotary, prism are shown as vectors.

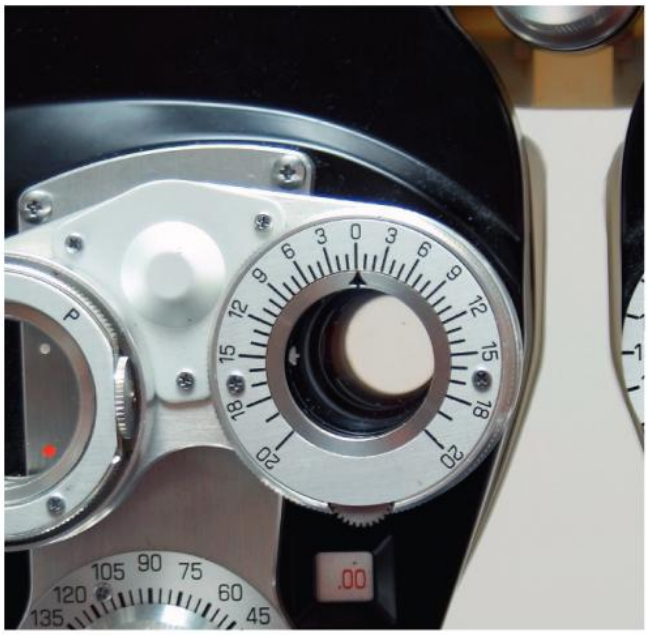


Figure 15.25 Measuring phorias and vergences makes use of a Risley, or rotary, prism. Here, the rotary prism is set to measure horizontal prism. Turning the small thumb gear at the bottom causes the two linked prisms to rotate in opposite rotational directions.

The same thing may be done to produce varying amounts of only horizontal prism. To produce only horizontal prism, begin with both prisms base left. Rotate the base of one prism clockwise and the other counterclockwise in equal amounts (Figure 15.24). Now horizontal prism varies, and vertical prism remains at zero.

There are two common forms of the Risley, or rotating, prism in ophthalmic practice. One, found on the phoropter, is used to measure phorias and vergences (Figure 15.25). The other is found on some lensmeters and is used to measure large amounts of prism in spectacle lenses (Figure 15.26).

HOW THE EFFECTIVE POWER OF A PRISM CHANGES FOR NEAR OBJECTS

A prism displaces a ray of light consistently. However, it will affect the eye somewhat differently when looking at a near object than it does when looking at a distant object. The eye will turn less when looking through a prism at a near object than it will when looking through that same prism at a distant object. Therefore, the *effective* power of the prism, when measured as the angle at which light enters the eye, will decrease as an object moves closer to the prism being worn. So, although a prism displaces a ray of light consistently, the power of the prism, when measured by the angle at which light enters the eye, will be less the closer the viewed object is to the prism.

For an object at infinity, a prism will cause that object to be displaced such that the angle of displacement, (d) equals the angle of rotation of the eye (d_e) (Figure 15.27). In other words, for distance vision, the prism causes the light to deviate, or bend, by the angle d. This is equal to the actual (effective) turn of the eye d_e.

For near vision, the light is also deviated the same amount by the prism as it is for distance because the prism itself is the same. The amount of deviation of the light by the prism is d as before. However, for near vision, light is diverging as it enters the prism (Figure 15.28). Although the ray of light is bent the same amount by the prism, the angle at which it enters the eye (d_e) is not as great as it was for distance vision. The effective deviation, d_e, is less than the angular deviation, d.

Figure 15.26 The auxiliary prism compensator found on some lensmeters measures high amounts of prism that would normally be beyond the limit of the viewed target area. This auxiliary prism is an example of a Risley, or rotary, prism. The red lettering is the amount of prism in one direction; the white lettering on the same ring shows the amount of prism in an opposite base direction. The degree lettering shows the orientation of prism base direction. When the compensating rotary prism axis is on zero, one direction on the prism power scale is base in and the other base out. When the compensating prism axis is on 090 (as shown here), one direction on the prism axis scale is base up and the other base down.

If we convert the angular measures d and d_e to prism diopters, P prism diopters correspond to d, and P_e prism diopters (effective prism diopters) correspond to d_e (effective deviation). By the definition of a prism diopter, we are able to say that:

$$\frac{P}{100} = \frac{y}{|l|}$$

The l is written as an absolute value because, by optical sign convention, the lens or prism is at the zero point on a number line. Distance measured from the prism to the right is plus and from the prism to the left is minus.

For the near diagram,

l = the distance from the prism to the near point,

s = the distance from the prism to the center of rotation of the eye,

y = the displacement of the image.

By the geometry as depicted in Figure 15.28

$$\frac{P_e}{100} = \frac{y}{|l| + s}$$

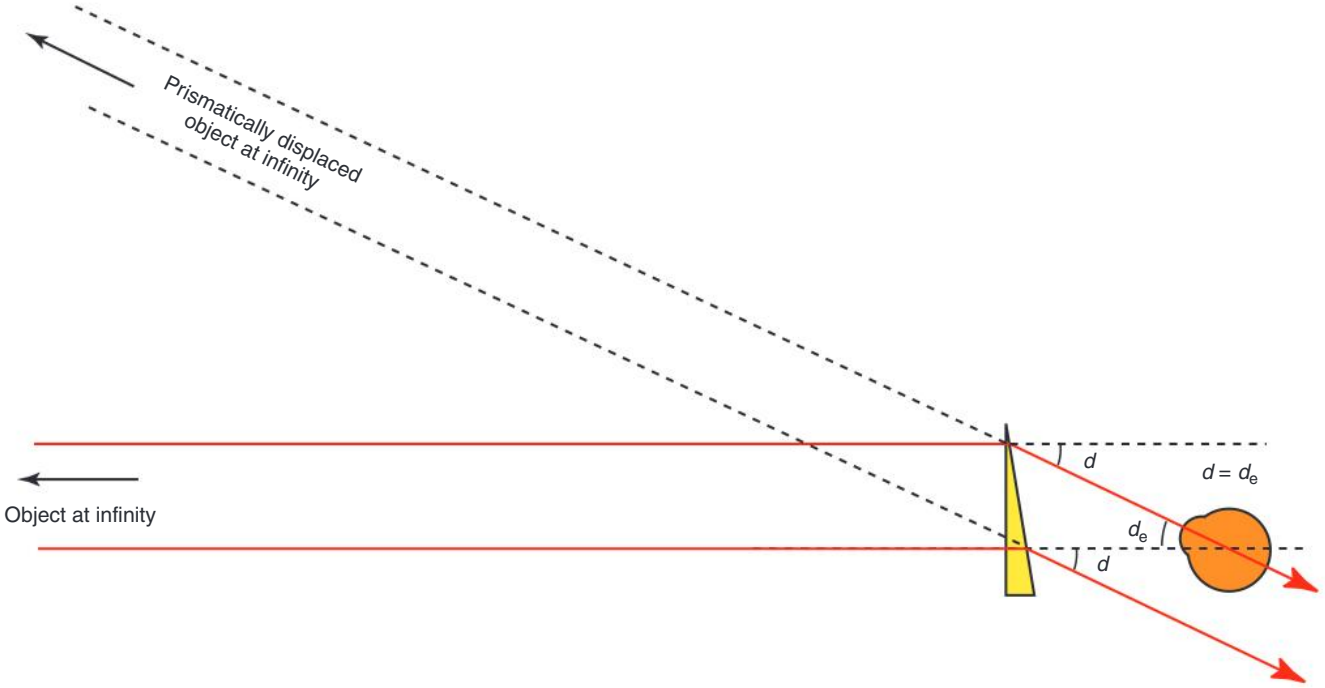


Figure 15.27 For light coming from infinity, a prism with an actual power of *P* will cause the light from that object to be displaced by the amount of deviation shown in the figure as *d*. d_e is the amount the eye must turn to see the object. For distance vision, these amounts are equal. When *d* and d_e are expressed in prism diopters, they are *P* and P_e, respectively. P_e is the effective power of the prism. Therefore, for distance vision, the actual power and effective power of the prism are the same.

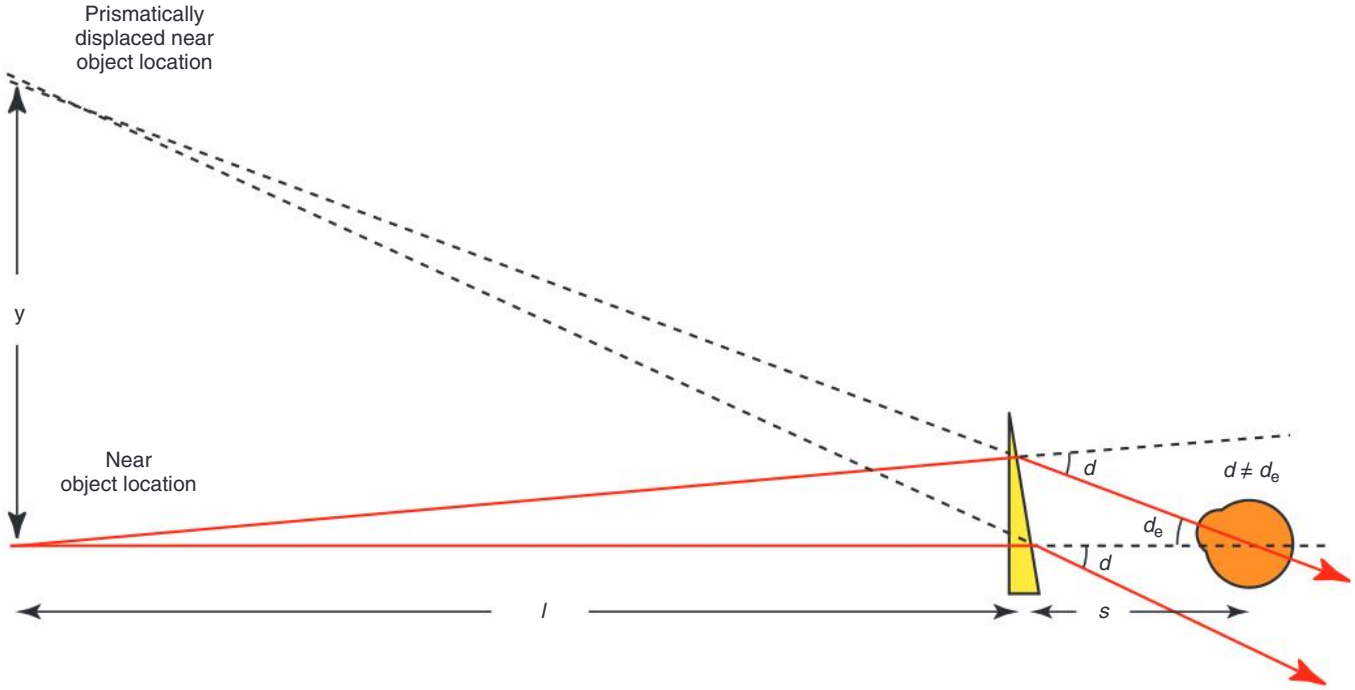


Figure 15.28 For near vision, light is diverging. Therefore, when it strikes the prism, it is bent the same amount (check the angle for each of the two rays). However, it enters the eye at a smaller angle. This causes the effective power of the prism (P_e) to be less than the actual power of the prism (*P*).

We know that in this instance our l value will be minus. So, in order to maintain sign convention and have the resulting equation work correctly, we write the two previous equations as:

$$\frac{P}{100}=\frac{y}{-l}$$

and

$$\frac{P_e}{100}=\frac{y}{-l+s}$$

By transposing the first equation, we get:

$$y=\frac{P(-l)}{100}$$

And by transposition, the second equation becomes:

$$y=\frac{P_e(-l+s)}{100}$$

Now, we have two values for y that must be equal to one another. Therefore, we can combine the two as:

$$\frac{P(-l)}{100}=\frac{P_e(-l+s)}{100}$$

This reduces to:

$$P(-l)=P_e(-l+s)$$

and becomes:

$$P_e=\frac{P(-l)}{(-l+s)}$$

When transposed, the result is what is referred to as the *effective prism power formula*:

$$P_e=\frac{P}{1-\frac{s}{l}}$$

So, the effective power of the prism for near objects can be compared mathematically with the actual power of the prism for objects at infinity with the above formula.

If expressed in words, the effective prism power formula reads:

$$\text{Effective prism power}=\frac{\text{Actual prism power}}{1-\frac{\text{Distance from prism to center of rotation}}{\text{Distance from prism to near object}}}$$

Example 15.16

A 5Δ base-in prism is prescribed for distance vision. The prism is worn at a vertex distance of 20 mm. What is the effective power of the prism for objects at 40 cm?

Solution

Before trying to solve by just using the equation, notice that vertex distance was given—not the distance to the center of rotation of the eye. If we use the effective prism power formula, we need to know the distance from the prism to the center of rotation of the eye. The unknown quantity is the distance from the front surface of the cornea to the center of rotation. This distance is usually assumed to be 13.5 mm. If we assume that the distance from the cornea to the center of rotation is 13.5 mm, then the distance from the prism to the center of rotation will be 20 mm + 13.5 mm, or 33.5 mm.

Note that because of sign convention, the distance from the lens (prism) to the near object is a negative number (−400 mm). So when putting the numbers into the formula we have:

$$\begin{aligned}\text{Effective prism power}&=\frac{5}{1-\frac{33.5}{-400}}\\&=\frac{5}{1-(-0.084)}\\&=\frac{5}{1.084}\\&=4.61\Delta\end{aligned}$$

The effective power of a 5.00Δ base-in prism, when used to view an object at 40 cm, is 4.61Δ base in.

Example 15.17

Suppose an object is at a distance of only −10 cm from a base-down prism having a power of 6Δ. If the prism is worn at a distance of 25 mm from the center of rotation of the eye, what is the effective power of that prism?

Solution

Since $l=-100$ mm, $s=25$ mm, and $P=6\Delta$, then

$$\begin{aligned}P_e&=\frac{P}{1-\frac{s}{l}}\\&=\frac{6}{1-\left(\frac{25}{-100}\right)}\\&=\frac{6}{1+0.25}\\&=4.8\Delta\end{aligned}$$

Note: As an object approaches the plane of the prism, the effective power of the prism continues to drop, losing power rapidly until the object finally touches the front of the prism and the effective power essentially drops to zero.

Important Notes on Effective Prism Power From a Clinical Perspective

Let's be realistic. In clinical practice, when does anyone ever calculate the effective power of a prism at near? Seldom, if ever. Why is this? It is because when testing for the needed amount of prism power at near, even though the marked power of the measuring prism is not the same as its effective power, if that marked amount of prism is ordered for the appropriate near working distance, it will still accomplish its intended purpose. It delivers the correct amount of needed prismatic effect.

It is more important to know what happens to the effective power of prism as the object moves closer to the plane of the prism lens than to be able to calculate the exact effective power that prism will have. Understanding the concept is more important. To help with this, here are a few conceptual trends.

- The labeled prism power designated on a diagnostic prism assumes that the object is at infinity. This is the maximum amount of effective prism power that the prism can provide.

- If the prism is used to view objects closer than infinity, the effective power of the prism starts to decrease from its labeled value.
- The loss of prism power as objects move closer to the prism starts slowly at first but accelerates as objects gets closer to the prism; eventually, as the object finally touches the front of the prism, the effective power of the prism becomes zero.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. A prism has an apical angle of 4.5 degrees and is made of plastic of index 1.49. What is the angle of deviation of the prism?
   a. 2.2 degrees
   b. 3.0 degrees
   c. 4.5 degrees
   d. 6.7 degrees
   e. none of the above
2. Using the simplified equation for thin prisms, find the angle of deviation for a prism having an apical angle of 5 degrees and an index of refraction of 1.5.
   a. 2.0 degrees
   b. 2.5 degrees
   c. 3.0 degrees
   d. 3.5 degrees
   e. 5.0 degrees
3. A prism with an apical angle of 9 degrees deviates light by 6 degrees. What is the refractive index of the prism material?
   a. 1.49
   b. 1.53
   c. 1.59
   d. 1.67
   e. 1.70
4. A person covers his or her left eye, and a prism is placed before the right eye. The base of the prism is oriented out toward the temporal side of the head. From the point of view of the person looking through the prism, in which direction will the image be displaced?
   a. to the right
   b. to the left
   c. upward
   d. downward
   e. There will be no displacement.
5. A prism deviates light 1.5 degrees. How many diopters of power does this prism have?
   a. 1Δ
   b. 1.5Δ
   c. 2.6Δ
   d. 0.9Δ
   e. none of the above
6. Light entering a prism in air is deviated in the direction of the:
   a. base.
   b. apex.
   c. base or apex, depending on the refractive index of the prism.
7. A prism displaces the image of an object at infinity 6 degrees upward. What is the power of the prism?
   a. 8.75Δ
   b. 99.50Δ
   c. 6.00Δ
   d. 10.51Δ
   e. none of the above
8. In the previous question in which the prism displaces the image of an object at infinity upward, what is the base direction of the prism?
   a. base up
   b. base down
   c. base in
   d. base out
   e. base at 6 degrees
9. How far will a prism with a power of 3.25Δ appear to displace the image of an object 4 m away?
   a. 3.25 cm
   b. 13 cm
   c. 1.3 m
   d. 12.3 cm
   e. none of the above
10. For a prism with a power of 6Δ, a point on the wall 6 m away will be made to appear how many centimeters away from its actual location?
    a. 1
    b. 6
    c. 36
    d. 60
    e. none of the above
11. An object is displaced 18 cm by a prism of unknown power. If the prism is 4 m from the object, what is the prism power?
    a. 0.22Δ
    b. 7.2Δ
    c. 4.5Δ
    d. 22Δ
    e. none of the above
12. If an image of an object 1.75 m away is displaced 1.75 cm, approximately what power is the prism?
    a. 1.75Δ
    b. 3.06Δ
    c. 0.10Δ
    d. 3.50Δ
    e. none of the above
13. An object is displaced 4 cm. If the prism is 0.50Δ in power, how far away is the object?
    a. 2 m
    b. 20 cm
    c. 8 m
    d. 8 cm
    e. none of the above
14. One prism has a power of 25Δ; a second prism has a power of 25∇ (prism centrads). Which prism is stronger in its ability to deviate light?
    a. The 25Δ prism
    b. The 25∇ prism
    c. The prisms are equal.
15. A prism has its base direction to the wearer's left. What base direction is this when referencing the wearer's right eye?
    a. Base down
    b. Base up
    c. Base in
    d. Base out

16. A prism has its base direction to the wearer's left. What base direction is this when referencing the wearer's left eye?
    a. Base down
    b. Base up
    c. Base in
    d. Base out
17. A prescription is written with prescribed prism of 2.0Δ base in for the right eye. How would this be written in the 360-degree laboratory system?
    a. 2.00Δ base 000
    b. 2.00Δ base 180
    c. 2.00Δ base 090
    d. 2.00Δ base 270
18. Suppose a prescription calls for prism in the left lens. The amounts are:
    3.00Δ base in
    1.50Δ base up
    What is this when written as one prism? (Give amount and base direction.)
    a. 3.00Δ base 153
    b. 3.25Δ base 153
    c. 3.35Δ base 153
    d. 3.50Δ base 153
    e. 4.50Δ base 153
19. A prescription for prism for the left eye reads:
    4.00Δ base in
    2.00Δ base down
    Using the 360-degree polar coordinate laboratory reference system and written as one prism, what is the amount of prism and its base direction?
    a. 4.50Δ base 027
    b. 4.50Δ base 153
    c. 4.50Δ base 207
    d. 4.50Δ base 333
20. A prescription calls for prism in the left lens as follows:
    5.00Δ base in
    2.00Δ base up
    What is this when written as one prism? (Give amount and base direction.)
    a. 5.38Δ base 022
    b. 5.38Δ base 158
    c. 5.38Δ base 202
    d. 5.38Δ base 338
21. Expressed in the 360-degree polar coordinate system, a right lens has a prism of 4.00Δ base 330. What prismatic effects and base directions would this be when written using the rectangular coordinate system?
    a. 3.50Δ base out and 2.00Δ base up
    b. 3.50Δ base in and 2.00Δ base up
    c. 3.50Δ base out and 2.00Δ base down
    d. 3.50Δ base in and 2.00Δ base down
22. True or false? The prism pair (R: 2 BI, L: No prism) will give the same net prismatic effect binocularly as (R: No prism, L: 2 BO).
    a. True
    b. False
23. True or false? The prism pair (R: 2 BI, L: No prism) will give the same net binocular prismatic effect as (R: 1 BI, L: 1 BI).
    a. True
    b. False
24. True or false? The prism pair (R: 2 BU, L: No prism) will give the same net prismatic effect binocularly as (R: No prism, L: 2 BU).
    a. True
    b. False
25. A prism with a base direction of base 180 is placed in front of the right eye. This prism has the same net binocular prismatic effect on the two eyes as if it had been placed how?
    a. Base 090 in front of the left eye
    b. Base 180 in front of the left eye
    c. Base 000 in front of the left eye
    d. Base 270 in front of the left eye
26. Which lens pair does not give the same net prismatic effect as all the others when worn? Stated another way: You are comparing all the five answers against one another. Four of the five give the same net binocular prismatic effect. Which one does not? (To answer this question, you should not have to do any calculations.)
    a. R: 1Δ base up, 1Δ base out
    L: 1Δ base down, 1Δ base out
    b. R: 1.41Δ base 135
    L: 1.41Δ base 315
    c. R: 2Δ base up
    L: 2Δ base out
    d. R: 0.50Δ base out
    L: 2Δ base up, 1.5Δ base out
27. In the lensmeter, a left lens has prism that reads 2.00Δ base at 150 degrees. Resolve this prism into vertical and horizontal components to nearest quarter diopter.
    a. 1.00Δ base up, 1.75Δ base out
    b. 1.00Δ base up, 1.75Δ base in
    c. 1.75Δ base up, 1.00Δ base out
    d. 1.75Δ base up, 1.00Δ base in
28. A 3.00Δ base-up prism is combined with a 4.00Δ base-in prism before the left eye. What is the compounded prism and its base direction that results from this combination?
    a. 5.00Δ base 037
    b. 5.00Δ base 053
    c. 5.00Δ base 127
    d. 5.00Δ base 143
29. Prism base 45 degrees before the right eye is the same as prism base:
    a. up and out
    b. up and in
    c. down and out
    d. down and in
    e. cannot be determined
30. What is the prism resulting when these two obliquely crossed prisms are combined before the right eye? (Give your answer first in the rectangular coordinate system and then in the polar coordinate system.)
    5.00Δ base 037
    5.00Δ base 143
    a. 8.00Δ base up or 8.00Δ base 090
    b. 6.00Δ base up or 6.00Δ base 090
    c. 8.00Δ base out or 6.00Δ base 180
    d. 6.00Δ base in or 6.00Δ base 000
31. What is the prism resulting when these two obliquely crossed prisms are combined before the left eye? (Give your answer first in the rectangular coordinate system and then in the polar coordinate system.)
    2.5Δ base 053
    2.5Δ base 217
    a. 0.50Δ base up and 0.50Δ base in or 0.71Δ base 135
    b. 0.50Δ base up and 0.50Δ base out or 0.71Δ base 045
    c. 1.00Δ base up and 4.00Δ base out or 4.13Δ base 014 degrees
    d. 1.00Δ base up and 4.00Δ base in or 4.13Δ base 166 degrees

32. Two equally powered prisms are yoked together to form a Risley prism. One prism is oriented base left, the other base right. As the prisms are turned, what happens?
    a. Horizontal prism begins to decrease.
    b. Horizontal prism begins to increase.
    c. Vertical prism begins to decrease.
    d. Vertical prism begins to increase.
33. What is the effective power of a prism with a power of 6Δ when viewing an object at a 20-cm viewing distance?
    a. 6.99Δ
    b. 6.00Δ
    c. 5.25Δ
34. A person is wearing 4Δ base-down prism before the right eye and a 4Δ base-up prism before the left eye. What is the effective power of the prisms at 40 cm if the lenses are worn at a vertex distance of 12 mm and the distance from the cornea to the center of rotation of the eye is 13.5 mm?
    a. 3.76Δ base down right eye and 3.76Δ base up left eye.
    b. 4.00Δ base down right eye and 4.00Δ base up left eye.
    c. 4.24Δ base down right eye and 4.24Δ base up left eye.
35. The single-vision lens wearer described in the previous problem occasionally works at a very close 15-cm working distance. What is the effective power of his prism prescription for this working distance?
    a. 4.42Δ base down right eye and 4.42Δ base up left eye.
    b. 4.00Δ base down right eye and 4.00Δ base up left eye.
    c. 3.97Δ base down right eye and 3.97Δ base up left eye.
    d. 3.42Δ base down right eye and 3.42Δ base up left eye.

16

Optical Prism: Decentration and Thickness

DECENTRATION OF SPHERES

When light goes through the optical center (OC) of a lens, it goes straight through. It is not bent. When light goes through any other point on a lens with refractive power, the ray of light is bent. The farther from the OC that a light ray strikes a lens, the more that ray will have to bend so that it will pass through the focal point of the lens. This lens characteristic may be used to advantage when prescribed prism is required in a prescription. However, it will also cause problems if the lens has not been properly centered before the eye.

A Centered Lens

At the exact OC of a lens, front and back lens surfaces are parallel to each other. The line that passes through the OC of a lens is known as the *optical axis*. Light from an object at infinity is focused somewhere on the optical axis. The exact location of the focal point depends on the power of the lens.

If the optic axis of a lens passes through the center of the pupil, the lens is centered in front of the eye. If the lens is moved so that it does *not* coincide with the line of sight of the eye (for our purposes at the center of the pupil), it is said to be *decentered*.

A Decentered Lens

Normally, an individual wearing corrective lenses has each lens positioned with its OC in front of the eye. In this position, when the wearer looks straight ahead, there is no displacement of objects from their actual positions (Figure 16.1).

What happens when the lens is moved so that the center of the lens is no longer in front of the center of the eye? To understand what happens, consider the shape of a plus lens. From the side (in cross section), it appears to look much like two prisms placed base to base (Figure 16.2). A minus lens gives the impression of being a combination of two prisms but this time placed apex to apex (Figure 16.3). When the wearer looks right through the center of the lens, the object is not displaced from its actual location. But when a plus or minus lens is moved off-center in relationship to the location of the eye, the object appears displaced as shown in Figures 16.2 and 16.3. This means that a *decentered* lens causes a *prismatic effect*.

Prism Amount Calculation Using Prentice's Rule

You may recall from Chapter 15 that prism power is measured in prism diopters, with a prism diopter being defined as the amount of light displaced in centimeters at a distance 1 m away from the lens or prism.

The relationship between focal length (f') and decentration (c) is shown in Figure 16.4 using similar triangles. This relationship is the same as the definition of prism power: the displacement in centimeters over the distance in meters.

By similar triangles, as shown in Figure 16.4, B and C, we see that:

$$\frac{c\,(\text{in cm})}{f'\,(\text{in meters})} = \frac{\text{Image displacement (in cm)}}{1\text{ m}}$$

And we know from the definition of a prism diopter that:

$$\Delta = \frac{\text{Image displacement (in cm)}}{1\text{ m}}$$

Therefore, we can see that:

$$\frac{c}{f'} = \Delta$$

So if we know lens decentration (c) in centimeters and lens focal length (f') in meters, the prismatic effect caused by the decentration may be calculated.

Because

$$F = \frac{1}{f'}$$

the relationship further simplifies to:

$$\Delta = cF$$

The equation $\Delta = cF$ is commonly known as *Prentice's rule*. Prentice's rule is extremely useful and is essential for understanding prism. It is worth noting that this is one of the few optics formulas that uses centimeters instead of meters.

Note also that Prentice's rule uses the dioptric power (F) without a plus or minus sign, since we do not denote negative prism diopters.

Prentice's rule shows us that any time a lens with dioptric power is decentered, a prismatic effect is created.

Example 16.1

If a lens having a power of +3.00 D is decentered 5 mm away from the center of the eye, how much prismatic effect will this cause?

Solution

To find the prismatic effect, simply multiply the distance *in centimeters* that the lens has been displaced times the power of the lens. Since 5 mm equals 0.5 cm,

$$\text{Prism diopters} = 0.5 \times 3.00$$
$$\Delta = 1.5$$

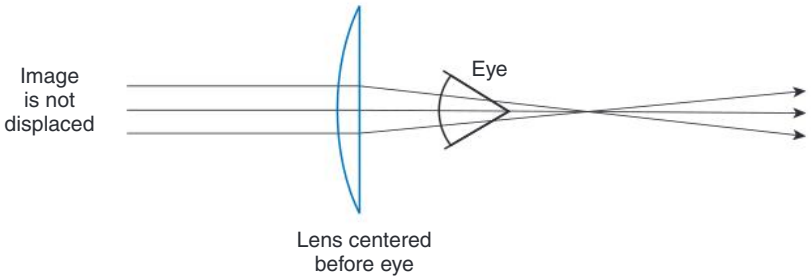


Figure 16.1 When a lens is positioned with its optical center directly in front of the eye, there is no prismatic effect.

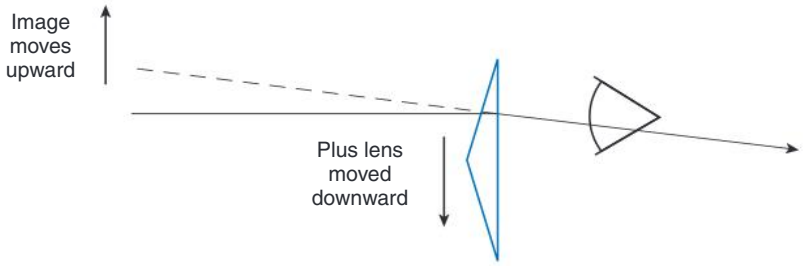


Figure 16.2 Moving the optical center of a plus lens downward will produce a base-down prismatic effect.

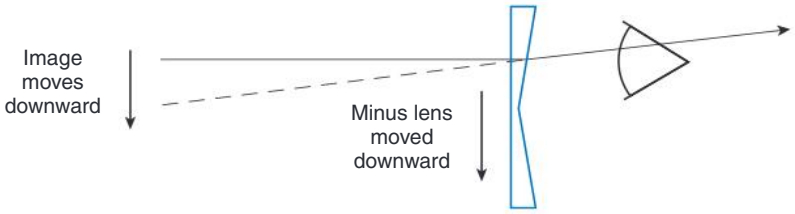


Figure 16.3 Moving the optical center of a minus lens downward will produce a base-up prismatic effect.

Prism Base Direction With Decentration

Prentice's rule permits us to calculate the amount of prism, but it does not give any indication to the location of the prism base. The prism base orientation depends on (1) the direction of decentration and (2) whether the lens is plus or minus.

As noted before, a plus lens resembles two prisms placed base to base. Both bases are at the center of the lens. Therefore, for a plus lens, the base direction created by decentration will correspond to the direction of the decentration. A plus lens decentered down will result in prism with the base down (see Figure 16.2).

A minus lens resembles two prisms placed apex to apex. Both apices are together at the center of the lens. Thus, if a minus lens is decentered down, the result will be prism with the base up, opposite to the direction of decentration (see Figure 16.3).

Example 16.2

If a −4.00 D spherical lens is decentered 5 mm upward, how much of a prismatic effect is induced, and what is the base direction?

Solution

Prentice's rule is used to find the prismatic effect.

$$\Delta = cF$$

In this instance,

$$\Delta = (0.5)(4.00) = 2.00$$

(Normally when using Prentice's rule, the absolute value of the lens power is used. Plus and minus signs are ignored.)

The decentration induces 2.00Δ of prism. Since the lens is minus in power, the base direction is opposite to that of the decentration. Therefore, the complete answer is 2.00Δ base down.

Example 16.3

A + 6.50 D lens before the right eye is decentered 3 mm nasalward. What amount of prism is induced, and what is the base direction?

Solution

Prentice's rule is again applied as follows:

$$\Delta = cF$$

$$\Delta = (0.3)(6.50) = 1.95$$

The lens is plus, so the base direction corresponds to the direction of decentration. Since nasalward is inward, the base direction is in. This gives a final answer of 1.95Δ base in.

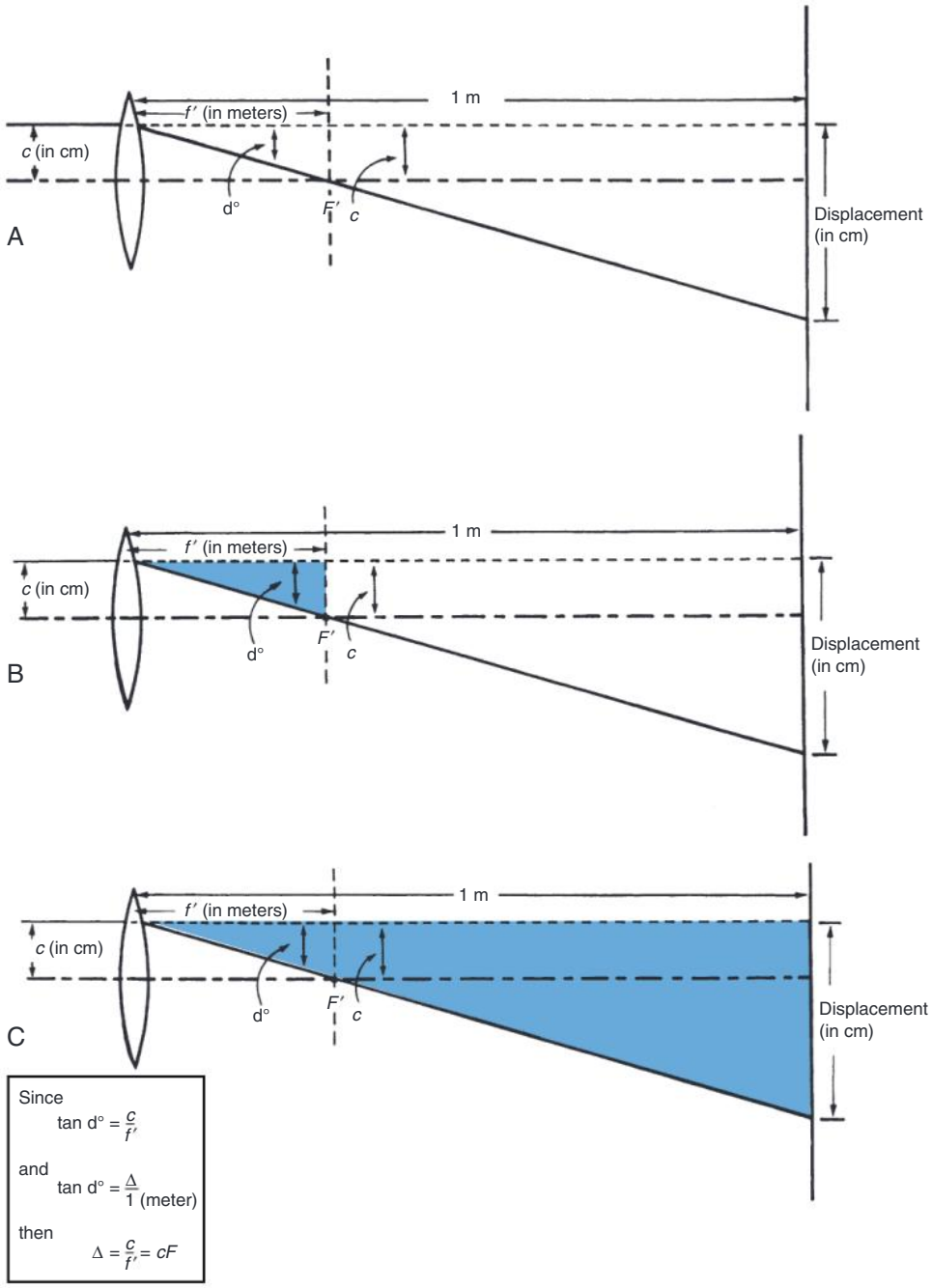


Figure 16.4 **A,** When a lens is decentered, the geometry of the displaced ray as it travels through the lens focal point may be illustrated as shown. **B,** Because the deviated ray passes through the focal point, degrees of deviation (d) may be found from the two known parameters (f' and c) by using the relationship:

$$\tan d = \frac{c}{f'}$$

C, Once a value for d is known, it can be seen from the figure how a prism value expressed in prism diopters may be established. From this relationship, Prentice's rule may be derived as shown in the boxed equation at the bottom left of the figure.

Example 16.4

A + 4.00 D sphere lens is ordered for the right eye. The prescription also calls for 2Δ base-out prism before the right eye. How should the lens be decentered to obtain the correct amount of prism?

Solution

This time, the missing parameters are the amount and direction of decentration. The amount is found by a simple algebraic transformation of Prentice's rule.

$$\Delta = cF$$
$$c = \frac{\Delta}{F}$$
$$c = \frac{2}{400}$$
$$= 0.5\,\text{cm}$$

Because the lens is plus, decentration must also be outward. The lens must be decentered 5 mm out.

Example 16.5

The following glasses are ordered:

OD : −5.00 D sphere
OS : −5.00 D sphere
PD = 60 mm

An exceptionally large frame is chosen. The frame is so large that it will not allow the correct interpupillary distance (PD) unless an extra-large lens blank is used. Using conventional lens blanks will not allow enough decentration. A gap is created temporally where there is not enough lens material to fill the frame. If the blanks were to be used anyway, the situation would require an incorrect placement of the lenses at a PD of 64 mm. How much prism would be induced and in what direction if this wrong PD is used?

Solution

The problem is shown diagrammatically in Figure 16.5. If the lenses have their OCs 64 mm apart, each lens is erroneously decentered 2 mm outward from the line of sight. It can be seen from the figure that the induced prism is base in (opposite the direction of decentration).

Prentice's rule shows that:

$$\Delta = (0.2)(5.00)$$
$$= 1\Delta$$

The incorrect lens placement was done in order to avoid using large lens blanks. However, doing so would cause 1Δ base in of unwanted prism before each of the two eyes.

Horizontal and Vertical Decentration of Spheres

When a sphere lens is decentered both horizontally and vertically, the most straightforward solution for finding the prismatic effect is to consider each component by itself.

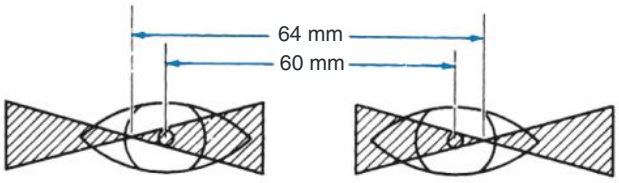


Figure 16.5 For a minus lens, a cross-sectional view suggests two prisms apex to apex. By visualizing the movement of these two prisms before the eyes in decentration, solving for base direction is considerably simplified.

Example 16.6

If a + 3.50 D sphere is decentered 4 mm in and 5 mm down, what is the resulting prismatic effect?

Solution

In this situation, the two decentrations may be handled independently.

The horizontal decentration results in:

$$\Delta = (0.4)(3.50) = 1.40$$

or 1.40Δ base in

The vertical decentration gives:

$$\Delta = (0.5)(3.50) = 1.75$$

or 1.75Δ base down

In most cases, these results may be left written as is. If a single compounded prism is desired, it may be calculated in the manner previously described in Chapter 15 in the section *Compounding and Resolving Prism*.

Example 16.7

A right lens of power −7.00 D sphere is decentered 3 mm out and 4 mm up. What are the resulting horizontal and vertical prismatic effects?

Solution

The horizontal component is:

$$\Delta = (0.3)(7.00) = 2.10$$

or 2.10Δ base in

This is shown in Figure 16.6, *A*.

The vertical component is:

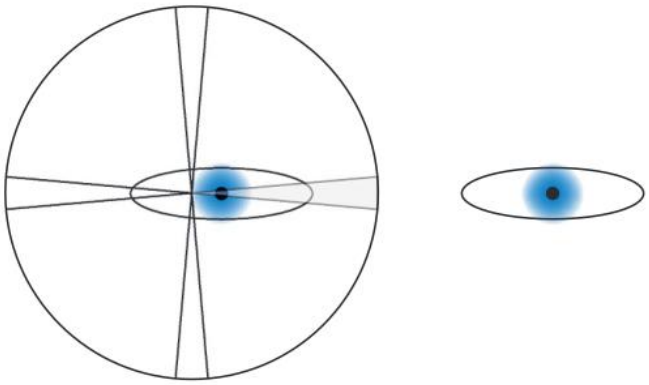
$$\Delta = (0.4)(7.00) = 2.80$$

or 2.80Δ base down

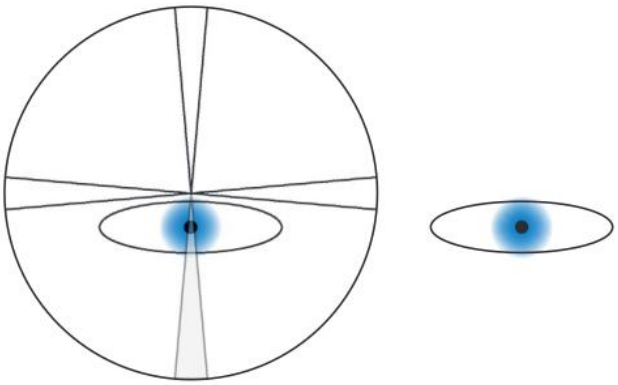
which is shown in Figure 16.6, *B*. The combined decentration is shown in Figure 16.6, *C*.

Oblique Decentration of Spheres

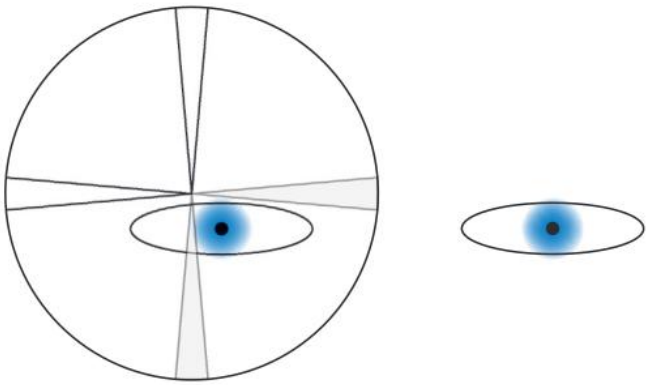
When a sphere lens is decentered in an oblique direction, the resulting prismatic effect and base direction will also be along the same meridian of decentration.



A



B



C

Figure 16.6 **A,** The −7.00 D sphere lens has been decentered 3 mm out, resulting in base-in prism. **B,** The −7.00 D sphere lens has been decentered 4 mm up, producing a base-down prismatic effect. **C,** The combined up and out movements have produced prism base down and base in. It may be expressed as two prismatic effects, or these two prismatic effects may be combined into one single prism.

Example 16.8

A right lens of power –7.00 D sphere is decentered 5 mm up and out along the 127-degree meridian. What is the resulting prismatic effect and base direction?

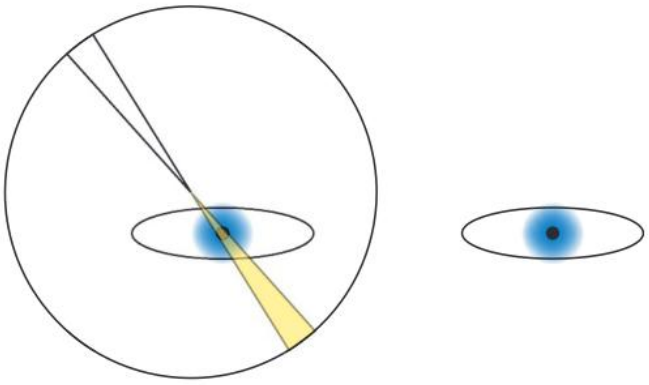


Figure 16.7 An oblique decentration of a sphere lens produces prism in the same meridian as the meridian of decentration.

Solution

The prismatic effect for this lens decentration is:

$$\Delta = (0.5)(7.00) = 3.50\Delta$$

The base direction for a minus lens is exactly opposite the direction of decentration. Therefore, the base direction is

$$(127) + (180) = 307 \text{ degrees}$$

So, the resulting prismatic effect and base direction is 3.50Δ base 307 (Figure 16.7). A 307-degree base direction is base down and base in for a right eye.

Notice that the previous two examples are really identical. Decentering a lens 3 mm out and 4 mm up is the same thing as decentering that same lens 5 mm up and out along the 127-degree meridian. If we resolve 3.50Δ base 307 into its horizontal and vertical components, we would find it to be 2.10Δ base in and 2.80Δ base down. Likewise, if we compound the 2.10Δ base in and 2.80Δ base down, we would find it to be 3.50Δ base 307.

DECENTRATION OF CYLINDERS

Cylinders produce varying prismatic effects when decentered. These prismatic effects depend not only on the power of the cylinder, but also on the orientation of the cylinder axis.

Decentration of Cylinders Along Major Meridians

If the axis of a plano-cylinder is oriented in the direction of decentration, there will be no prismatic effect induced regardless of the amount of decentration. This is because there is no power in the axis meridian of a plano-cylinder. If, however, the cylinder axis is at right angles to the direction of decentration, the amount of prism induced varies according to Prentice's rule.

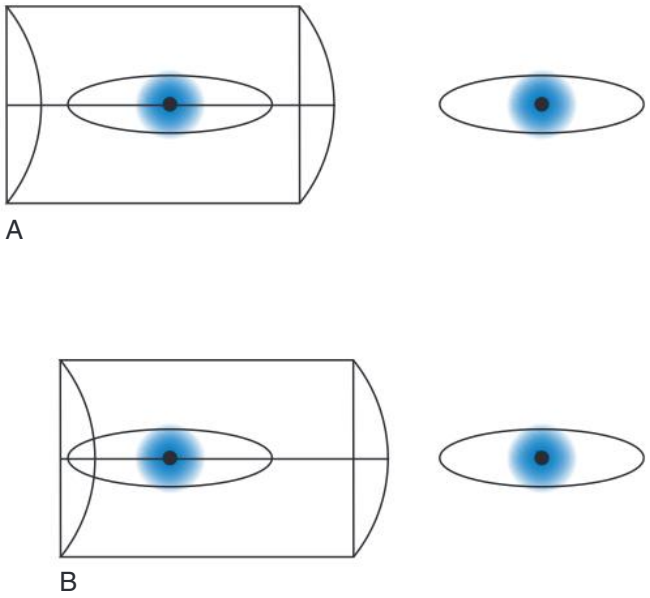


Figure 16.8 The cylinder in **A** is producing no prismatic effect. **B,** Even though the plus cylinder lens has been decentered to the right, there is still no prismatic effect produced. The eye is still looking through a point on the cylinder axis.

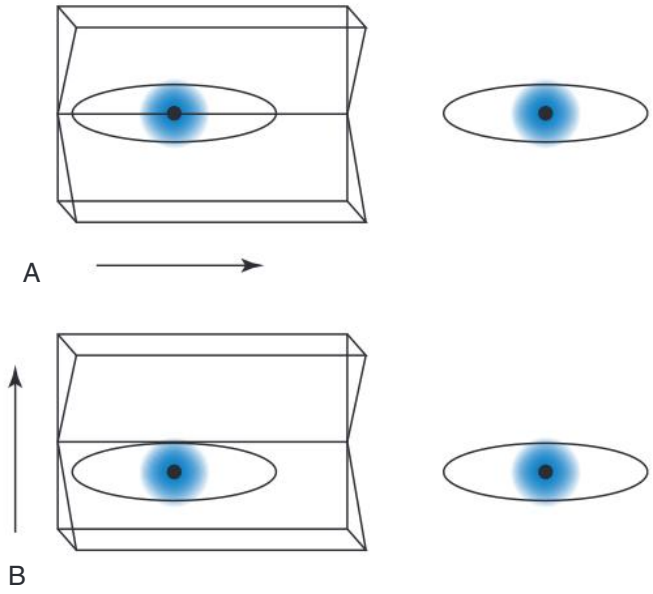


Figure 16.9 If a minus cylinder axis 180 is moved 3 mm to the right, then 3 mm up there is no prismatic effect caused by the horizontal movement to the right. When the cylinder is moved at right angles to the cylinder axis, there will be a prismatic effect just as with spheres. **A,** No prismatic effect. The eye is looking through the axis. It will still be looking through the axis even after the lens is moved 3 mm to the right. **B,** The minus-powered cylinder lens was moved 3 mm to the right and then moved 3 mm up. The base direction of the prismatic effect produced is down. The base-down prismatic effect is due only to the vertical movement.

Example 16.9

A plus cylinder lens of power pl +5.00 × 180 is decentered 5 mm to the right. What prismatic effect is produced?

Solution

Because the lens is decentered along the 180-degree meridian, it is the power in meridian 180 that we use as the *F* within Prentice's rule.

$$\begin{aligned}\Delta &= cF\\ &= (0.5)(0)\\ &= 0\end{aligned}$$

The decentration is along the axis meridian as shown in Figure 16.8. As long as the eye is looking through any point along the axis of a plano-cylinder, there is no prismatic effect.

With plano-cylinder lenses, the prism power induced depends only on how far the axis of the cylinder is from the original position. In most cases, the original position will be the pupil center. It does *not* necessarily depend on how far the lens was moved.

To illustrate, imagine that the cylinder lens in the above example was first decentered 3 mm inward and *then* 3 mm upward (Figure 16.9). The horizontal decentration will have no prismatic effect at all. The second decentration—3 mm upward—still has the same effect of 0.60Δ. The question is somewhat akin to asking how far a straight ruler will be from a certain point on the ground if, while remaining in contact with that point, the straight ruler is slid 3 cm to the right and then lifted 3 cm above the point. Of course, the shortest distance from point to ruler is still 3 cm.

Example 16.10

How much prism will be induced and in what direction will the base be oriented by decentering a pl −2.00 × 180 right lens a distance of 3 mm upward?

Solution

Placing the prescription on a power cross reveals that the vertical meridian is −2.00 D in power. Decentering upward causes a base-down prismatic effect for a minus-powered lens. Prism amount is readily determined by:

$$\begin{aligned}\Delta &= cF\\ &= (0.3)(2.00)\\ &= 0.60\Delta\end{aligned}$$

The prism induced is 0.60Δ base down.

Example 16.11

A pl +4.00 × 090 cylinder is decentered 5 mm up and 2 mm out. What is the resulting prismatic effect?

Solution

The 5 mm vertical decentration has no prismatic effect at all. This is because the cylinder axis is also up and down (axis 90). However, the horizontal 2 mm out movement is at right angles to the cylinder axis. The horizontal decentration causes this prismatic effect.

$$\begin{aligned}\Delta &= cF\\ &= (0.2)(4.00)\\ &= 0.80\Delta\end{aligned}$$

The lens is plus in power. Therefore, the base direction is the same as the direction of decentration. The prismatic effect caused by both vertical and horizontal decentration is purely horizontal (i.e., 0.80Δ base out).

Decentration of Cylinders Oriented Obliquely

When decentering a plano plus cylinder or a plano minus cylinder, the resulting prismatic effect is always at right angles to the axis of the cylinder. In other words, if a plus cylinder with axis 090 is decentered, the resulting base direction will always be along the 180-degree meridian. It will always be either base 0 or base 180. When a plano-cylinder is decentered, there are only two possible base directions. Both are 90 degrees away from the axis of the cylinder.

Example 16.12

A cylinder is oriented with its axis along the 120-degree meridian. It is then decentered. What are the only two possible resulting prism base directions?

Solution

There are only two possible answers, regardless of direction of decentration. Both are 90 degrees away from the cylinder axis. This means that one base direction is 120 + 90, or 210 degrees. The other is 120 – 90, or 30 degrees.

To solve a decentration problem for an oblique cylinder, one of the simplest methods represents a combination of graphical and algebraic methods. This method helps in understanding the concept of what is happening when an oblique cylinder is decentered. (Note: One may ask if there are other mathematical or graphical methods for calculating the prismatic effects of decentering an oblique cylinder. The answer is yes. However, most are complex and are now more appropriately carried with computers in the optical laboratory. Our purpose is to allow one to anticipate what can and does happen when oblique cylinders are either intentionally or unintentionally decentered.)

Example 16.13

A right lens has a cylinder power of +4.00 × 030. What prismatic effects will be caused by the cylinder if the lens is decentered 3 mm outward?

Solution

If such a lens were properly oriented before the eye, it would appear as shown in Figure 16.10, *A*. To solve this problem, a graph is constructed showing the axis position of the lens after the 3-mm decentration has taken place (see Figure 16.10, *B*). The power of a cylinder lens is at right angles to the axis. A line is therefore drawn from the point of origin (in this case the eye) to the cylinder axis, meeting the axis line at right angles (see Figure 16.10, *C*). When drawn to scale, this line can be measured and is found to be 1.5 mm long. (Note: It helps to draw 1 cm for each 1 mm of decentration. If a drawing is too small, the result cannot be measured accurately enough.) The distance to this point on the axis is termed the *effective decentration* and is abbreviated d_e because the result is the same as if the cylinder lens were decentered to this point.

Alternately, it is possible to find the effective decentration (d_e) trigonometrically. Here is how this would be done.

Look at Figure 16.10, *D,* to see how the axis of the cylinder, the effective decentration line, and the horizontal decentration form three sides of a right triangle. The 30-degree cylinder axis angle is the angle used with the sine function. Since:

$$\sin 30 = \frac{\text{Opposite}}{\text{Hypotenuse}} = \frac{\text{Effective decentration}}{\text{Horizontal decentration}}$$

$$0.5 = \frac{\text{Effective decentration}}{3\,\text{mm}}$$

$$\text{Effective decentration} = (0.5)(3) = 1.5\,\text{mm}$$

Because the effective decentration of the cylinder is 1.5 mm away from the point of origin to the axis, the power of the prism may be determined using Prentice's rule.

$$\Delta = (0.15)(4.00) = 0.60\Delta$$

The eye is looking through that part of the *plus* cylinder *below* the axis, making the base direction *above* the eye. There are only two possible base directions—base 120 or base 300. (Both are 90 degrees away from the cylinder axis.) And since the base direction is above the eye, or upward, the correct base direction is 120.

The induced prism is 0.60Δ base at 120 degrees. When prism base direction is expressed in degrees, the polar coordinate system is being used.

If needed, this prism may be further resolved into horizontal and vertical components. (This is the rectangular coordinate system and was explained previously in Chapter 15.) If resolved, it will be found that even though the decentration is purely horizontal, the majority of induced prism will be vertical. By way of review, here is how it is done.

The base of the prism is 120 degrees. When drawn in Figure 16.10, *E*, the right triangle needed for our calculations is 120 minus 90, or 30 degrees. The horizontal prism component is found from:

$$\sin 30 = \frac{\text{Opposite}}{\text{Hypotenuse}} = \frac{H}{0.6}$$

$$0.5 = \frac{H}{0.6}$$

$$H = (0.6)(0.5) = 0.30\Delta$$

The vertical prism component is:

$$\cos 30 = \frac{\text{Adjacent}}{\text{Hypotenuse}} = \frac{V}{0.6}$$

$$0.866 = \frac{V}{0.6}$$

$$V = (0.6)(0.866) = 0.52\Delta$$

So, expressed in the rectangular coordinate system instead of the polar coordinate system of degrees, the resulting prism amounts are 0.30Δ base out and 0.52Δ base up.

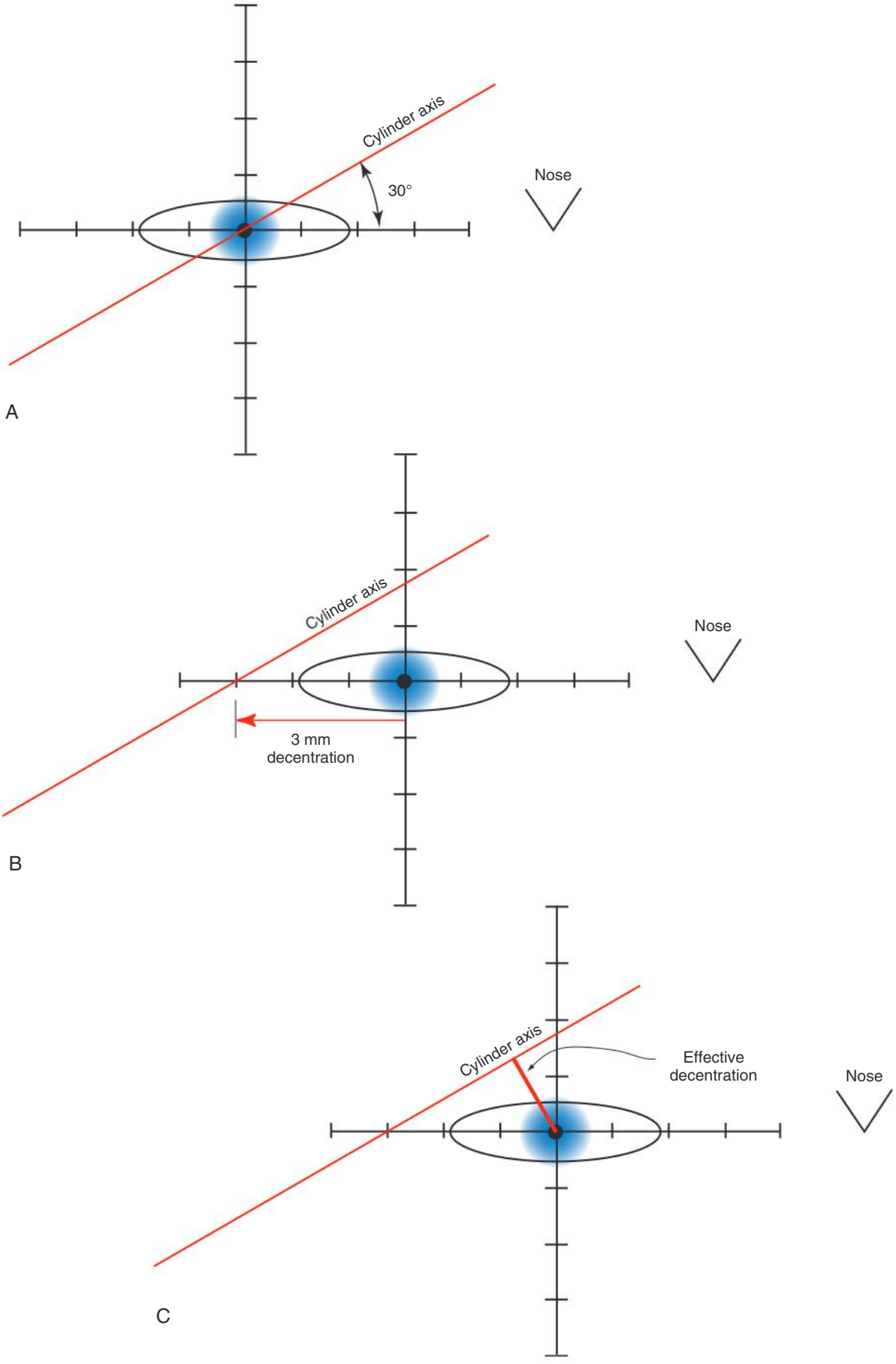


Figure 16.10 **A,** A nondecentered lens having a cylinder component allows the axis of the cylinder to pass through the pupil center. **B,** Decentering a cylinder lens 3 mm outward does not really move the axis 3 mm away from the pupil center. (The pupil remains at the origin of the *x*-, *y*-axes.) **C,** To find the power and base orientation of the induced prism, the shortest distance to the cylinder axis is determined.

Continued

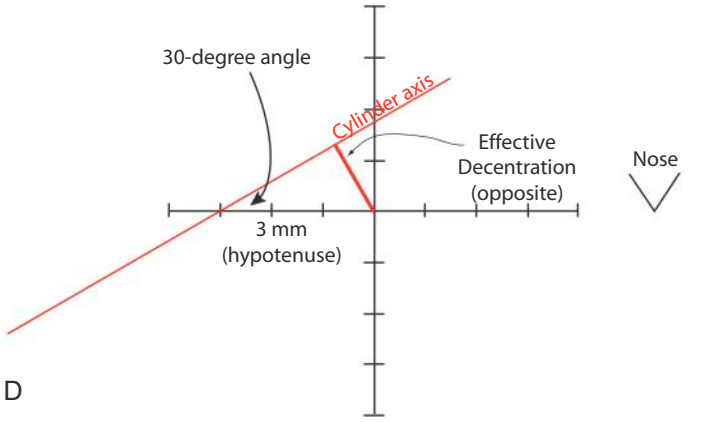


Figure 16.10—cont'd **D,** The effective decentration of a lens may be found with trigonometry, as shown here. The sine of the angle in the right triangle is the opposite over the hypotenuse. The opposite is d_e. The hypotenuse is 3 mm. **E,** When specified using the polar coordinate system, the prism amount is 0.6Δ and the base direction is 120. However, when using trigonometry to find the equivalent horizontal and vertical prism amounts, the angle to use within the right triangle is 30 degrees (120 – 90 = 30 degrees). Now, it is possible to find the horizontal component using the sine of 30 degrees and the vertical component using the cosine of 30 degrees.

Example 16.14

A left lens has a power of *pl* – 4.00 × 045. The lens is decentered 4 mm outward from the pupil center. What is the amount and base direction of the prism induced?

Solution

A properly positioned plano-cylinder will place the axis across the pupil center, as shown in Figure 16.11, *A*. When the cylinder lens is decentered 4 mm outward, prism is induced. The base direction will be either base 135 or base 315. The eye is looking above the cylinder axis. Since the cylinder is minus, the prism direction is away from the axis and has an "up" component. Therefore, the only possible prism base direction is base 135, which can be resolved into both base up and base in prism (see Figure 16.11, *B*).

When drawn to scale, the shortest distance from pupil location to the cylinder axis, which is the effective decentration (d_e), can be found by direct measurement. Direct measurement will give a value close to the correct amount.

Alternately, the effective decentration could also be found more exactly starting from the geometry of the figure (Figure 16.12). Using trigonometry,

$$\sin 45 = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$= \frac{d_e}{4\,\text{mm}}$$

$$0.707 = \frac{d_e}{4\,\text{mm}}$$

$$d_e = (0.707)(4) = 2.83\,\text{mm}$$

The cylinder axis is 2.83 mm from the pupil. This effective decentration in centimeters multiplied by the cylinder power will give the amount of prism caused by the decentration.

Therefore, the prism power is found by:

$$\Delta = cF$$

$$\Delta = (0.283)(4.00)$$

$$\Delta = 1.13$$

So the answer is 1.13Δ base 135 (Figure 16.13, *A*). The prism found may be resolved into separate horizontal and vertical components as shown in Figure 16.13, *B*, giving 0.80Δ of base-in prism and 0.80Δ of base-up prism.

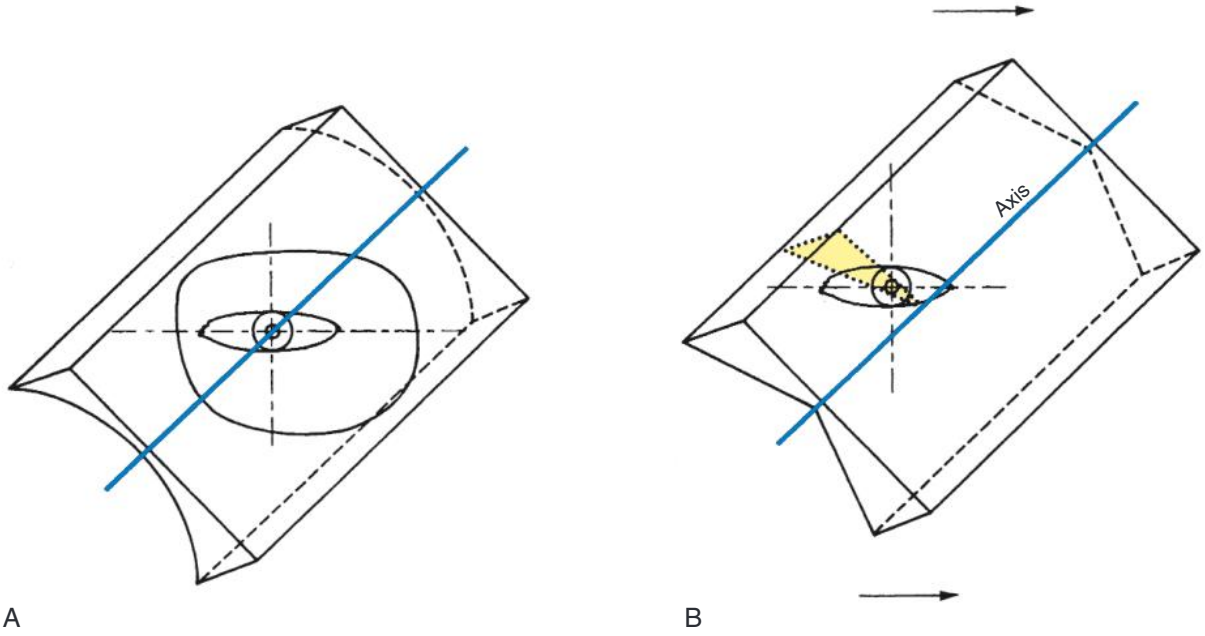


Figure 16.11 **A,** An obliquely oriented minus cylinder lens with a cylinder axis of 045. This appears drawn schematically before the eye as shown here. **B,** If this same oblique cylinder is decentered from its previous location by a purely horizontal movement, it will cause a prismatic effect with an obliquely oriented base direction. Since the eye is a left eye and the cylinder has an axis of 045, the base direction is base 135.

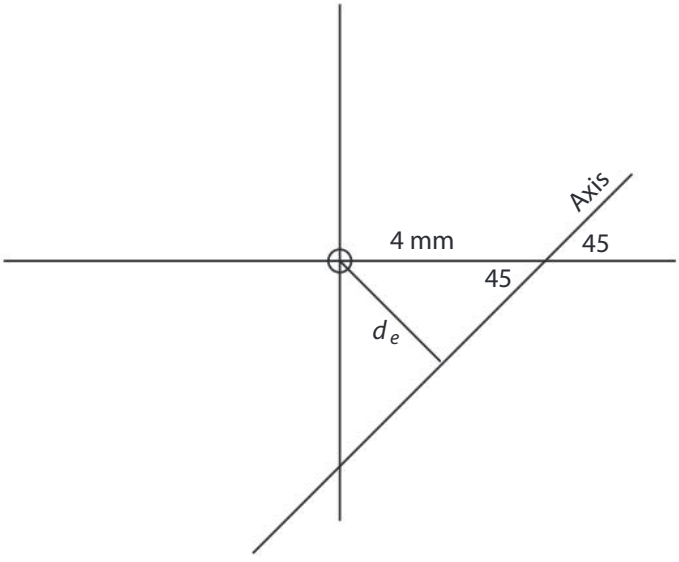


Figure 16.12 Here, the effective decentration (d_e) is found using the sine of the 45-degree angle.

$$\sin 45 = \frac{\text{Opposite}}{\text{Hypotenuse}} = \frac{d_e}{4}$$

Horizontal and Vertical Decentration of Oblique Cylinders

Prism induced by decentration of a cylinder lens both horizontally and vertically is found in the same manner as just described. To summarize:

1. From the starting point (usually the eye), decenter the lens horizontally and vertically to find the location of the decentered point.
2. Draw the cylinder axis line through that decentered point.
3. Drop a perpendicular from the cylinder axis to the starting point (usually the eye) to find the effective decentration.
4. Find the induced prism amount by multiplying the effective decentration in centimeters by the power of the cylinder.
5. Find the prism base direction. There are two possible choices. Both are 90 degrees away from the cylinder axis. Choose which of the two possible base directions is correct.

DECENTRATION OF SPHEROCYLINDERS

A solution for prismatic effects induced by a spherocylinder lens may be found in several different ways:

1. Calculate for the sphere and cylinder separately, and combine the results.
2. Transpose the prescription to crossed cylinder form. Each cylinder may then be worked independently and the results combined.
3. Use higher mathematical computations.

Perhaps the easiest way is to simply calculate the sphere and cylinder independently. Then, results from the sphere decentration and results from the cylinder decentration are combined for the final answer.

Spherocylinders With Axes 090 or 180

The easiest way to understand how to find the prism caused by decentering a spherocylinder lens is to start with one that has a cylinder axis of either 090 or 180.

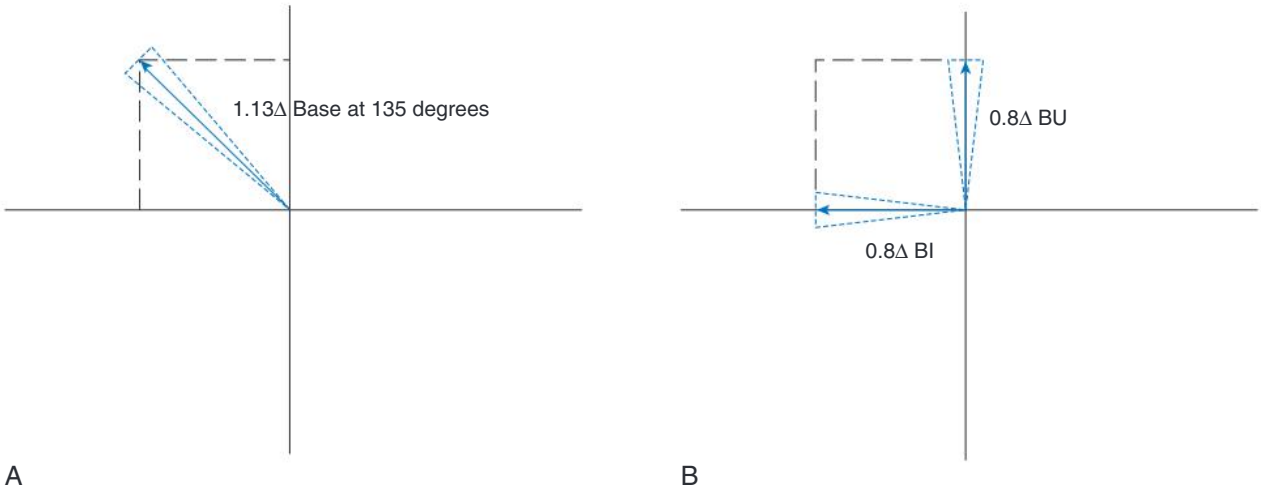


Figure 16.13 **A,** A 1.13Δ prism base at 135 degrees may be drawn as a vector. **B,** The 1.13Δ prism vector resolves into horizontal and vertical components, both having 0.80Δ of prism power. *BI,* Base in; *BU,* base up.

Example 16.15

A right lens has a power of +3.00 – 2.00 × 090. The lens is decentered 7 mm out and 2 mm up. What is the prismatic effect induced?

Solution

Consider the sphere first. The horizontal component is:

$$\Delta = cF$$
$$= (0.7)(3.00)$$
$$= 2.1\Delta$$

Because the sphere is plus, the base direction will be the same as the direction of decentration. So, the horizontal component is 2.1Δ base out.

The vertical component of the sphere is:

$$\Delta = cF$$
$$= (0.2)(3.00)$$
$$= 0.6\Delta$$

Since decentration for this plus lens is up, the base direction is up, resulting in 0.6Δ base up.

For the cylinder, the axis is 090, or vertical. The full amount of the cylinder power is in the horizontal meridian. Here are the calculations for that meridian.

$$\Delta = cF$$
$$= (0.7)(2.00)$$
$$= 1.4\Delta$$

Because the cylinder is a minus cylinder, the base direction induced by the cylinder will be opposite the direction of decentration, or base in, resulting in 1.4Δ base in. Because there is no cylinder power in the 90-degree meridian, the 2-mm vertical decentration is along the cylinder axis and causes no vertical prism.

Now, we add the prismatic effects for sphere and cylinder together. The total horizontal prismatic effect is:

$$(2.1\Delta \text{ base out}) + (1.4\Delta \text{ base in}) = 0.7\Delta \text{ base out}$$

There is only one vertical component of 0.6Δ base up. These horizontal and vertical components may be left as they are or compounded into a single oblique prism.

Note: When the direction of decentration is in the same meridian as one of the major meridians of the cylinder, it is easier to draw a power cross and consider each meridian. In this example, the horizontal meridian would have a power of +1.00.

$$\Delta = \frac{c}{F}$$
$$= (0.7)(1.00)$$
$$= 0.7\Delta$$

The vertical meridian remains the same. Even though this method is easier when the cylinder axis is either 090 or 180, it will not work in the case of an oblique cylinder. So, next we will consider the case of a spherocylinder with an oblique axis.

Spherocylinders With an Oblique Axis

Calculating prism for spherocylinders with an oblique axis is done with the same general procedure as was described previously. That is, first the sphere is considered by itself, and then the cylinder is considered by itself. Combine the horizontal components and then the vertical components.

Example 16.16

A left lens has a power of +5.00 – 4.00 × 045. The lens is decentered outward 4 mm from the pupil center. What is the amount and base direction of the prism induced?

Solution

If a + 5.00 D sphere lens is decentered 4 mm outward, the amount of prism induced will be:

$$\Delta = cF$$
$$= (0.4)(5.00)$$
$$= 2.00\Delta$$

Because the lens is plus and is decentered outward, the base direction is outward and the prism is 2.00Δ base out. There is no vertical component.

Notice that the cylinder is the same one as was given in Example 16.14. When that cylinder was decentered 4 mm outward, the resulting prism was 1.13Δ base 135. This prism

was resolved into separate horizontal and vertical components, giving 0.80Δ base up and 0.80Δ base in.

If we add the horizontal prism components together for the sphere and the cylinder, we have 2.00Δ base out and 0.80Δ base in. The net result is 1.20Δ base out. There is only one vertical component—the 0.80Δ base up caused by the cylinder. Therefore, the induced prism for the complete spherocylinder lens is 1.20Δ base out and 0.80Δ base up. Again, we could choose to leave this in the prescriber's method or compound the two values to produce a single oblique prism in the 360-laboratory method.

Ground-In Prism Versus Prism by Decentration

As we have seen in the previous sections, prism may be created by the decentration of a powered lens. Prism may also be created by grinding the surface of the lens at an angle during the surfacing process.

For regular nonaspheric single vision lenses, there is no optical difference between prism created by decentration and prism that has been ground in. Neither is superior nor inferior to the other. It may be that it is possible to create a thinner prismatic lens by surfacing instead of by decentering a finished lens. That is an issue of lens blank thickness rather than prism quality, however.

PRISM THICKNESS

Thickness Differences Between Prism Base and Apex

A prism causes light to change direction. This is because light must pass through two surfaces that are not parallel with one another. Because the surfaces are at an angle to one another, the prism is thin at the top (apex) and thick at the bottom (base). Prismatic power is determined by the angle the front and back surfaces make with one another and by the refractive index of the material. Because lens surfaces of a prism are angled, adding prescribed prism to a lens will cause a change in lens thickness.

Knowing the thickness difference between the base and apex of a prism allows the amount of prism to be found using the formula:

$$P = \frac{100g(n-1)}{d}$$

where

P = the amount of prism,
g = the difference in thickness between the apex and the base of the prism,
n = the refractive index of the lens material, and
d = the distance between the apex and base of the prism.

See Figure 16.14 and be sure to read the caption carefully.

The thickness difference (g) between the top and bottom of the prism can also be found if the amount of prism is known by simply rearranging the formula to read:

$$g = \frac{dP}{100(n-1)}$$

The prism thickness formula is reliable for all lenses and not just plano prisms. It does not matter if the lens has a plus or minus refractive power. The thickness difference between measured points is still a predictor of prism power halfway between those two points.

Example 16.17

A lens is made from a material having an index of refraction of 1.5. It is 50 mm in diameter. The top of the lens is 2 mm thick, and the bottom of the lens is 5 mm thick. How much vertical prism is present in the middle of the lens?

Solution

We may use the formula:

$$P = \frac{100g(n-1)}{d}$$

to find the answer.

In this example, the thickness difference (g) between the top and the bottom of the lens is:

$$g = 5 - 2 = 3\,\text{mm}$$

The diameter of the lens is 50 mm, and the index of refraction as 1.5. Therefore, we may substitute those values in the prism thickness formula to find:

$$P = \frac{100 \times 3 \times (1.5-1)}{50}$$
$$= \frac{300 \times (0.5)}{50}$$
$$= 3\Delta$$

Notice in this particular circumstance, when the index is near 1.5 and the diameter is 50, that the thickness difference in millimeters is a direct predictor of prism amount.

Example 16.18

Suppose we have a −6.50 D lens that is made from polycarbonate (index = 1.586). The lens is edged oval for a frame with an A dimension of 48 mm. The nasal edge has a thickness of 4.2 mm, and the temporal edge is 5.8 mm thick. What horizontal prismatic effect is found exactly in the center of the lens?

Solution

To find the answer, we again use the prism thickness formula:

$$P = \frac{100g(n-1)}{d}$$

In this case,

$$g = 5.8 - 4.2 = 1.6\,\text{mm}$$

$$d = 48\,\text{mm, and}$$

$$n = 1.586$$

Substituting these values in the formula, we get:

$$P = \frac{100 \times 1.6 \times (1.586-1)}{48}$$
$$= \frac{160 \times (0.586)}{48}$$
$$= 1.95\Delta$$

Because the temporal edge is thicker than the nasal edge, the prism base is temporalward, or base out. So the amount of horizontal prism present in the middle of the lens is 1.95Δ base out. (Note: even though the −6.50 D refractive power of the lens was given in the problem, it was not needed to determine prism.)

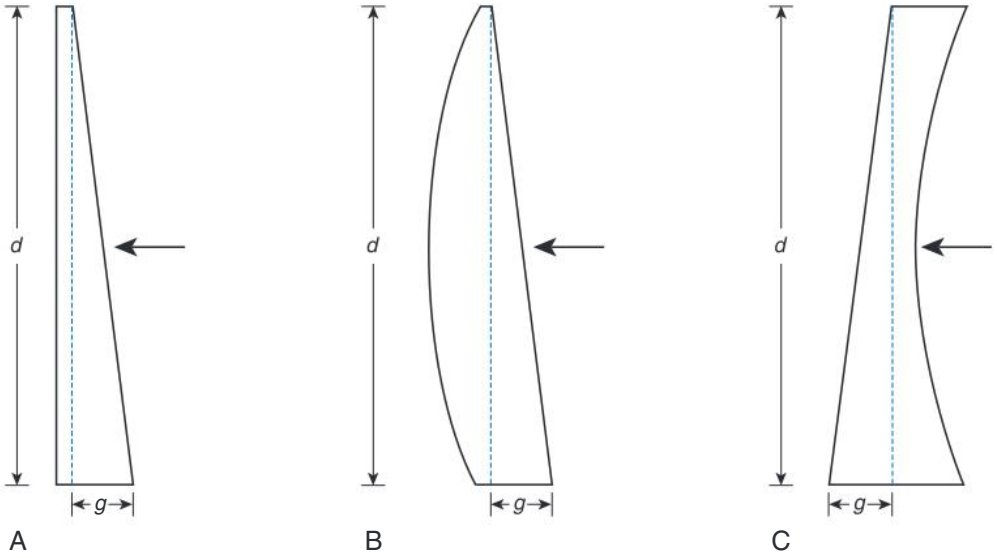


Figure 16.14 When using the prism thickness formula,

$$P = \frac{100\, g\,(n-1)}{d}$$

d is the distance between the two measured points and *g* is the thickness difference between those two measured points. The prismatic effect, *P*, is found at the halfway point between the two points measured for thickness. Note that in **A,** the dimension marked as *g* does not go the full width of the lens where the prism base is located. The *g* dimension is the width of the top of the prism lens subtracted from the width of the bottom of the prism lens (i.e., the thickness difference). For the plus lens, **B,** the prismatic effect at the halfway point (marked with an arrow) is the same as **A** even though the lens has a refractive dioptric power. This is because the thickness difference, *g*, is the same for both lenses. **C,** This lens is a minus lens. Even though the lens has minus power, the same thickness difference principle holds. The prismatic effect at the point halfway between the measured points is independent of the refractive power of the lens. In these figures, the measured points were the tops and bottoms of the lenses. However, they would not have to have been measured at the edges of the lenses. Thickness difference will determine the prismatic effect halfway in between the two measured points in the meridian of measurement, regardless of where the points are measured. To summarize, in **A,** the prism amount is the same across the entire lens because the prism has only prism power (Δ) and does not have refractive power (D). In **B** and **C,** where the lenses have refractive power as well, the prismatic effect is calculated for the halfway point but will vary at other points across the lens. The amount calculated is for the halfway-between point only.

How Prescribed Prism Affects Lens Thickness

If prism is present in a lens, the lens thickness at the OC will change. Most of the time it is assumed that a lens will be thicker by one half of the prism thickness difference, or ½ *g* when prism is present, regardless of how the prism base direction is oriented. This simplifies the problem, but it is not always true. The base direction determines just how much the prescribed prism will change the center or edge thicknesses. How this works is summarized in Box 16.1 and explained in the following sections.

Plus Lenses

With most pairs of glasses, each lens is normally decentered inward. This is because the wearer's intertpupillary distance (PD) is usually less than the "frame PD." (The frame PD is the sum of the frame A plus the distance between lenses.) For plus lenses, after the lens is in the frame, the thicker portion of the lens edge will then be found nasally and the thinner portion temporally (Figure 16.15, *A*). Now to add the prism.

BOX 16.1 Lens Thickness Changes for Prescribed Prism

Plus Lenses

Base in: Center thickness increases by one-half the prism thickness difference.

Base out: Center thickness decreases by up to the full thickness difference, depending on the amount of decentration present.

Vertical prism with small frame *B:* Center thickness does not change.

Vertical prism with large frame *B:* Center thickness increases by up to one-half the thickness difference.

Minus Lenses

Base in: Center thickness increases slightly. (The optical center [OC] is the thinnest spot on the lens, and it is displaced with prescribed prism. Note the difference between center thickness and minimum thickness.)

Base out: Center thickness increases slightly (The OC is the thinnest spot on the lens, and it is displaced with prescribed prism.)

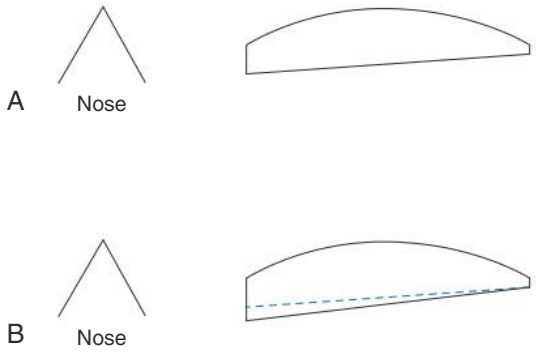


Figure 16.15 **A,** Plus lenses that have been decentered inward to correspond to the wearer's interpupillary distance are thicker nasally. **B,** If base-in prism is prescribed for the plus-lens wearer, the lens will be thicker still.

Base-in prescribed prism. If prescribed prism is added to a plus lens and positioned *base inward*, the thickest portion of the lens will become even thicker (see Figure 16.15, *B*). The thinner temporal portion must retain the same minimum thickness. Therefore, the center thickness of the lens will increase by an amount equal to almost half of the difference between the base and apex thicknesses.

This increase in center thickness is necessary because the prescribed prism will be located where the OC of the lens had been located. With prescribed prism, this location now becomes the major reference point (MRP)—often referred to as the prism reference point (PRP).

Example 16.19

A plus-powered crown glass lens with a diameter of 54 mm is calculated to have a center thickness of 3.4 mm without prescribed prism being considered. If the prescription also calls for 2.5Δ of base-in prism, what will happen to the center thickness?

Solution

To figure the thickness induced by the prism, we begin from the formula:

$$P = \frac{100g(n-1)}{d}$$

and transpose it to:

$$g = \frac{dP}{100(n-1)}$$

The thickness difference between the thick edge and the thin edge is thus,

$$g = \frac{(54)(2.5)}{100(1.523-1)} = 2.58\,\text{mm}$$

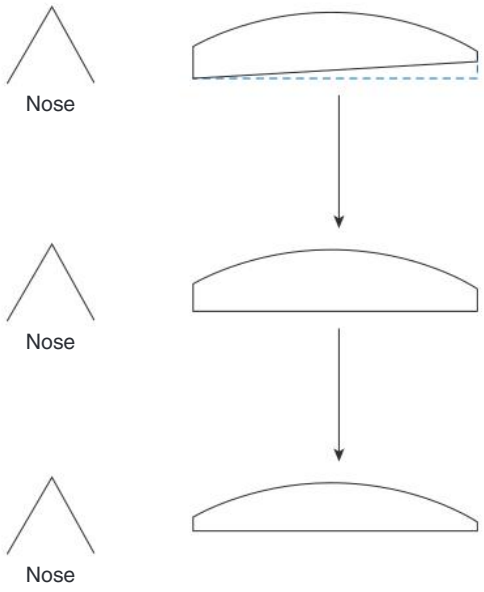


Figure 16.16 When base-out prism is prescribed for a plus-lens wearer, the lens will become thicker temporally. Now, because the thinnest edge is thicker, the whole lens may be thinned. (Note: Thinning should be done during the surfacing process in the optical laboratory. The possibility of thinning the whole lens may not be immediately evident. This could easily happen if the desired amount of prism is created by just decentering a finished single vision lens.)

The thickness in the center of the prism will be half of this value, or $\frac{g}{2}$.

$$\textit{Increase in center thickness} = \frac{g}{2} = \frac{2.58}{2} = 1.3\,\text{mm}$$

The new center thickness will be:

$$3.4 + 1.3 = 4.7\,\text{mm}$$

Base-out prescribed prism. If the prescribed prism is *base out*, the thicker portion of the prism is turned outward. This corresponds to the thinnest part of an inwardly decentered plus lens. If done right, the net effect will result in a lens that is closer to the same edge thickness both nasally and temporally. If the lens has enough center and nasal edge thickness, it may be *thinned* by an amount up to the full prism thickness difference (g). Therefore, a nasally decentered plus lens with base-out prescribed prism can be made thinner than it would be without prescribed prism (Figure 16.16).

Base-up or base-down prescribed prism. Small amounts of base-up or base-down prescribed prism will not affect the center thickness of the lens if the vertical (*B*) dimension of the frame is small compared with the *A* dimension. However, for prescriptions with larger amounts of prism or for frames with larger *B* dimensions, center thickness will be affected. The amount of center thickness increase may then approach one-half the calculated vertical prism thickness difference.

Minus Lenses

With minus lenses, the amount of prescribed prism affects edge thickness more than center thickness. *Base-out* prism increases the thickness of the temporal edge by an amount close to equal to the base thickness of the prism, depending upon the amount of decentration present.

Center thickness will increase somewhat when base-out or base-in prescribed prism appears in minus lenses. The thinnest point on the lens moves from the MRP to the location of the displaced OC as shown in Figure 16.17. (Note of Caution: Center thickness is normally checked near the physical center of the edged lens, shown as the MRP in Figure 16.17. However, the thinnest part of the lens is at the displaced OC. If a lens is to have a specific minimum thickness for safety purposes, it can be seen how it could be possible for a lens to end up with its minimum thickness thinner than what might be measured at the MRP.) It is easier to anticipate the effect of prescribed prism for plus lens thicknesses than for minus lens thicknesses.

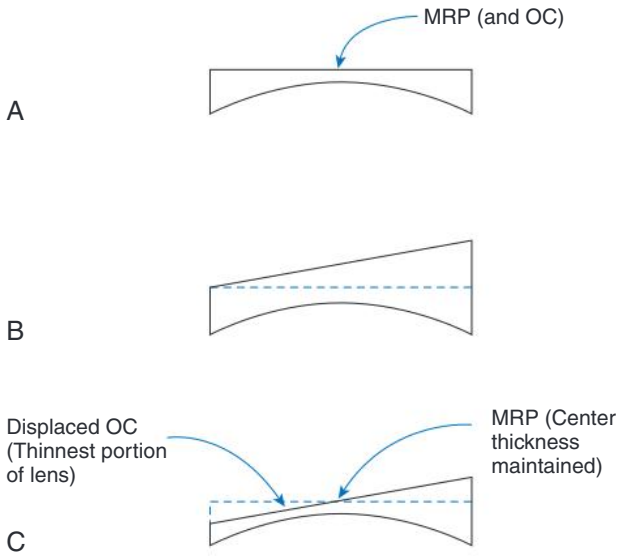


Figure 16.17 **A,** Here is a finished but unedged lens with no decentration and no prism. The major reference point (*MRP*) and optical center (*OC*) are at the same location. **B,** This minus lens has prism. Simply adding extra thickness to a minus lens by an amount equal to one-half the prism's apex-base thickness difference will cause the lens to be unnecessarily thick. **C,** Thinning a minus lens with significant prism back to a normal minimum thickness at the MRP will cause the minus lens to be excessively thin at the now-displaced OC. The displaced OC will be at a location other than the MRP.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. A +4.00 D lens is decentered 3 mm inward from the center of the pupil. What prismatic effect is induced, and what is its base direction?
   a. 12.00Δ base in
   b. 12.00Δ base out
   c. 1.20Δ base in
   d. 1.20Δ base out
2. A lens is decentered up 3 mm and creates a 2.10Δ base-down prismatic effect. What is the power of the lens?
   a. +0.75 D
   b. −0.75 D
   c. +7.00 D
   d. −7.00 D
3. A minus lens has its optical center displaced too far temporally. What kind of prismatic effect will be produced?
   a. Base in
   b. Base out
   c. Cannot tell from information given
4. A person wearing glasses with a right eye power of −1.25 + 0.25 × 180 requires 1.00Δ base-up prism. The frame is rectangular with a vertical dimension of 40 mm. How much decentration is required to create this amount of prism?
   a. 8 mm up
   b. 8 mm down
   c. 10 mm up
   d. 10 mm down
   e. None of the above
5. In verifying a pair of glasses, it is known that the wearer has an interpupillary distance (PD) of 60 mm. The distance between the centers of the lenses is 68 mm, and both of the lenses are −4.00 D. How much prism (to the nearest 0.25Δ) and in what base direction is being worn for both eyes together?
   a. 2.50Δ base in (BI)
   b. 1.50Δ base out (BO)
   c. 1.50Δ BI
   d. 3.25Δ BO
   e. 3.25Δ BI
6. A wearer has a PD of 70 mm. The distance between the OCs of a pair of −6.25 D lenses is 63 mm. There is no prism indicated on the spectacle prescription. How much total unwanted prism is present and in what base direction?
   a. 2.188Δ BI
   b. 2.188Δ BO
   c. 4.375Δ BI
   d. 4.375Δ BO
7. The prescribed glasses are for a person with right and left monocular PDs of 33 mm each. The prescription reads:
   R: −5.00 D sphere
   L: −8.00 D sphere
   The OCs were erroneously placed and are both found at 31 mm. What is the prismatic effect induced?
   a. 0.60Δ BO
   b. 0.60Δ BI
   c. 1.30Δ BI
   d. 2.60Δ BO
   e. 5.20Δ BI

8. A pair of glasses reads as follows in the lensmeter:
R: + 2.75 − 1.00 × 180
L: + 2.75 − 1.00 × 180
Distance between OCs is 76 mm. The wearer's binocular PD is actually 66 mm. How much prism and what is the base direction of that prism found in the glasses that this person is wearing? (Putting the prescription on a power cross may help in working the problem.)
a. 5.50Δ BO
b. 1.75Δ BO
c. 1.75Δ BI
d. 2.75Δ BO
e. 2.75Δ BI

9. A pair of glasses reads as follows in the lensmeter:
O.D.: −2.00 −1.00 × 180
O.S.: −3.00 −1.00 × 090
(Watch the cylinder axes.) Distance between OCs is 76 mm. (Both dots are equal distances from the center of the glasses.) The wearer's monocular PDs are 34 mm each. How much *total* prism and what base direction is being worn?
a. 1.60Δ BI
b. 2.00Δ BO
c. 2.00Δ BI
d. 2.40Δ BO
e. 2.40Δ BI

10. A glasses prescription is:
O.D.: −3.50 −1.00 × 090
O.S.: −5.50 −1.50 × 090
The binocular distance PD is 64 mm. To keep from using oversized blanks, one might be tempted to "push the PD" so that the OCs are 2 mm too far out per lens, giving a binocular PD of 68 mm. If this were to be done, how much *total* prismatic effect would be induced?
a. 2.30Δ BO
b. 2.30Δ BI
c. 1.80Δ BO
d. 1.80Δ BI
e. 1.65Δ BI

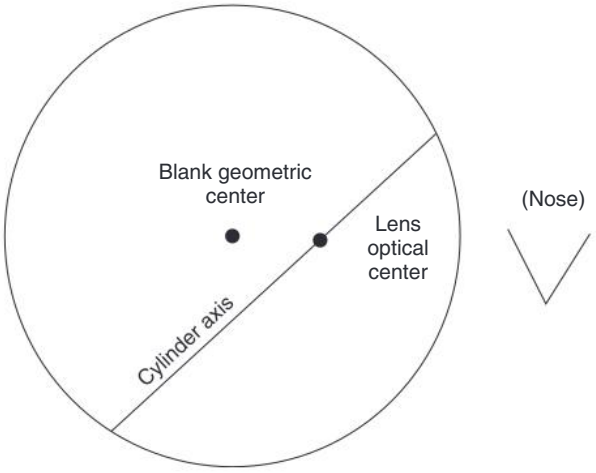
11. The following lenses are ordered:
−1.00 −1.75 × 090
−1.50 −1.75 × 090
The wearer's binocular distance PD is 59, and the frame chosen has a large eye size. When the glasses are returned from the laboratory, in dotting the lenses, the OCs are found to be 63 mm apart. The eyes have equal monocular PDs, and the optical centers are equidistant from the center of the frame. Using prevailing American National Standards Institute (ANSI) prism tolerance standards, is the 63 PD acceptable?
a. Yes
b. No
c. Insufficient information present

12. A right lens of a pair of spectacles is examined through the lensmeter. The lens is positioned so that initially the lensmeter stop is positioned on the horizontal midline of the lens and temporal to the lens geometric center. As the lens is moved to the operator's left, the target is observed to move from the lower half of the field (prism base-down effect) to the upper half. What may be said about the lens?
a. It contains prism.
b. It contains base-down prism.
c. It contains an oblique cylinder, with the axis of the minus cylinder between 90 and 180 degrees.
d. It contains an oblique cylinder with the minus cylinder between 0 and 90 degrees.
e. It is not possible to make any of the above statements with the information given.

13. A right lens of power pl −3.00 × 045 is decentered out. What is the resulting prismatic effect?
a. Base up and out
b. Base down and in
c. Base down and out
d. Base up and in
e. Base in

The following four questions (Questions 14–17) are concept questions and are based on the following information. You should not be doing any calculating.

The right lens shown below has already been surfaced and the OC moved nasally. This has been done because the frame is quite large. The lens is facing you, convex side up. There will be prism present at the location of the blank geometric center. Tell what prism base direction(s) you would expect at this location.



14. In this case, the lens being asked about is a + 4.00 D sphere. (Since this lens is a sphere and there is no cylinder, you should ignore the cylinder axis drawn on the lens.) What is the base direction?
a. Base in
b. Base out
c. Base up
d. Base down

15. Now, consider the lens shown in the figure to be a pl −3.00 × 040. What are the base directions?
a. Base in and up
b. Base out and up
c. Base in and down
d. Base out and down

16. If the lens shown in the figure is a plus cylinder lens with a power of +4.00 + 1.00 × 040, what are the base directions for the point in question?
a. Base in and up
b. Base out and up
c. Base in and down
d. Base out and down

17. If the lens shown in the figure has a power of +4.00 − 1.00 × 040, what would be the base directions for the point in question? (*Now the lens is a minus cylinder lens.*)
a. Base in and up
b. Base out and up
c. Base in and down
d. Base out and down

18. A right lens is −6.00 + 1.00 × 090 with 3.00Δ of base-in prism. How far nasalward or temporalward from the major reference point (MRP) is the OC?
a. 6 mm temporalward
b. 5 mm temporalward
c. 5 mm nasalward
d. 6 mm nasalward
e. None of the above

19. The following lenses are ordered:
pl −2.75 × 015
pl −2.75 × 165
PD = 63 mm
The glasses are verified and found to have a PD of 67 mm. Assume the wearer's eyes are symmetrically placed. Will this lens pass or fail ANSI Z80 Standards for unwanted horizontal and vertical prism? (Before you do any calculations, first look at the prescription carefully.)
a. It will pass for horizontal prism but fail for vertical prism.
b. It will pass for vertical prism but fail for horizontal prism.
c. It will fail for both horizontal and vertical prism.
d. It will pass for both horizontal and vertical prism.

20. A right lens having a power of pl +3.50 × 075 is decentered 5 mm out. How much prism, expressed as vertical and horizontal components, is induced?
a. 0.73Δ base out and 1.94Δ base up
b. 0.73Δ base up and 1.94Δ base out
c. 0.43Δ base up and 1.61Δ base out
d. 0.43Δ base out and 1.61Δ base up

21. A 1.80-index lens, edged oval, has a temporal edge thickness of 4.2 mm and a nasal edge thickness of 3.2 mm. The lens has an A dimension of 54 mm. What is the prismatic effect at the geometric center of the edged lens?
a. 1.60Δ
b. 1.48Δ
c. 0.92Δ
d. 0.74Δ

22. A right lens with a power of +4.75 D sphere has an index of refraction of 1.66. It is edged and in the frame. You dot the MRP of the lens. You measure the thickness of the lens at a point 20 mm nasal to the MRP and again at a second point 20 mm temporal to the MRP. The thickness of the lens 20 mm temporal to the MRP is 7.8 mm. The thickness 20 mm nasal to the MRP is 5.4 mm. What is the prismatic effect and base direction at the MRP?
a. 2.4Δ base in
b. 3.54Δ base out
c. 3.96Δ base out
d. 4.02Δ base in
e. 4.02Δ base out

23. We have an edged lens that is +3.25 D in power. It is edged to 50 mm round. The refractive index of the lens is 1.5. If the top of the lens is 1.2 mm thick and the bottom of the lens is 1.7 mm, how much vertical prism is present at the center of the lens halfway between the top and bottom? (Give your answer to the nearest quarter diopter of prism power.)
a. 0.50Δ
b. 0.75Δ
c. 2.00Δ
d. 2.25Δ

24. You have the following prescription:
R: +1.00 D sphere
L: +3.50 D sphere
The lenses are in a frame in which the A plus the distance between lenses of the frame is a good bit larger than the wearer's PD. You want to prescribe a total of 5Δ of base-out prism for right and left eyes. Of the following choices, to end up with the thinnest and lightest pair of lenses, which option would you choose?
a. R: 2.50Δ BO
L: 2.50Δ BO
b. R: 5.00Δ BO
L: No prism
c. R: 2.00Δ BO
L: 3.00Δ BO
d. R: 3.00Δ BO
L: 2.00Δ BO

25. All the prescriptions listed below are to be edged for a certain oval-shaped frame. The lens is decentered nasally for the wearer's PD. (For example, the frame could have a 50-mm eyesize and a 20-mm bridge size, and the wearer's PD could be 60 mm.) All of the prescriptions are surfaced to power to produce the thinnest possible lens. Of the prescriptions listed, which one will be the thickest lens?
a. +6.00 D sphere with no prescribed prism
b. +6.00 D sphere with 3Δ base-in prism
c. +6.00 D sphere with 3Δ base-out prism
d. +6.00 D sphere with 3Δ base-up prism

17

Fresnel Prisms and Lenses

WHAT IS A FRESNEL PRISM?

A traditional prism has two flat, nonparallel surfaces. Parallel light entering the prism is bent toward the base of the prism and leaves the back surface of the prism at an angle. A prism is thicker at the base than at the apex. The larger the prism, the thicker the base of the prism will be.

A Fresnel prism attempts to circumvent thickness by building a "tower" of small, wide prisms. To understand how a Fresnel prism works, imagine cutting off the tops of many equally powered prisms and gluing them, one above the other, onto a thin piece of plastic (Figure 17.1). Although a Fresnel prism is molded into one piece, its construction duplicates this imaginary example (Figure 17.2). A Fresnel prism is only 1 mm thick.

What Are the Advantages of a Fresnel Prism?

There are several advantages of Fresnel prisms made for ophthalmic purposes. First, it is very *thin and extremely lightweight*. It is *flexible* and can be applied to an existing spectacle lens, making it *possible to apply the lens in-house*, without an in-house optical laboratory.

Because the lens is made from a soft, flexible material, it *can be cut to any shape* with scissors or a razor blade. This means that it can be cut and applied to one sector of a lens. (Practical applications are explained later.)

Because conventional prisms have a large increase in thickness from apex to base, a high-powered prism is troubled by magnification differences and changes in power across the lens. Although Fresnel lenses do not eliminate this problem, they do *reduce magnification differences* considerably.

What Are the Disadvantages of a Fresnel Prism?

Fresnel prisms *look different* than conventional lenses. They are different enough that they may be noticed by others. Because Fresnel prisms have many small ledges, they are *harder to clean* than conventional lenses.

High-powered prisms will cause a *slight decrease in visual acuity*. Most of this is due to the chromatic aberration and distortion associated with prisms. This decreased acuity occurs in both conventional and Fresnel prisms. Fresnel prisms also cause a *slight loss of visual acuity caused by reflections* at the prism facets, especially under certain sources of illumination. Compared with acuity through conventional prisms, the minimal acuity decrease through Fresnel prisms may be slightly less than a line on a Snellen chart at a 90% contrast level.[1]

WHEN ARE FRESNEL PRISMS USED?

There are a variety of clinical applications for Fresnel prism. The following six sections discuss major applications.

High Amounts of Prism

Because of its thickness advantage, Fresnel prism is useful for high amounts of prism.

Use and Reuse

Fresnel prism lenses are easy to apply and remove. They may be used and reused. This is helpful when determining how a given prism amount will work long term or for use during vision therapy.

Sector Application

A partially paralyzed extraocular muscle may result in a different amount of prism being needed for different directions of gaze. A Fresnel prism can be cut to fit that particular lens area. Prism is present only where it is needed.

For Vertical Imbalance Correction

When a person may require a correction for vertical imbalance, Fresnel prism can be applied to the lower portion of existing lenses to see if a vertical imbalance correction of a certain amount will be helpful before it is ordered in a slab-off correction. (For more information on vertical imbalance correction, see Chapter 21.)

For Horizontal Prism for Near Working Distances

For a prescription with horizontal prism for near only, it is feasible to use Fresnel prism applied just to the lower portion of the lenses. (For more information on horizontal prism for near working distances, see Chapter 19.)

Visual Field Defects

With visual field defects, prism may be applied in one section of the lens with the base oriented in the direction of the defect and the apex of the prism close to the central visual area. This way, the eye travels only a short distance before it picks up the image through the prism. The image appears closer to the center and can be seen without moving the head.

A person may have a visual field defect in which, for example, the right half of the visual field is blind for both right and left eyes. The defect is called a *homonymous hemianopia*. Fresnel prisms can be applied to the right side of one or both lenses. In this instance, prism base direction would be base right. With prism in place, the wearer looks to the right but does not have to turn the head or eyes as far to see an object in the right-hand field of view.

Sector Prisms for Homonymous Hemianopia

Here is one method that has been used to measure for placement of prism on one-half of the spectacle lens in the case of homonymous hemianopia. With the spectacles properly adjusted on the wearer's face, the wearer looks into the viewing eye of the practitioner. The eye with the visual field loss nasally is occluded with a cover paddle. A near-point card or other straight edge is brought in from the temporal, nonseeing side of the other eye. When the subject first reports seeing the card, the location of the edge of the card is marked on the lens with a vertical line (Figure 17.3, *A*). The apex of the Fresnel prism is often placed 3 to 5 mm temporal from this position (see Figure 17.3, *B*)[2] but may be

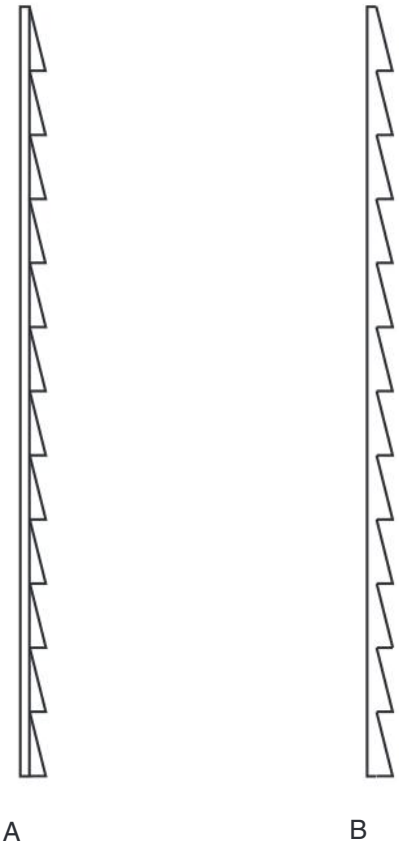


Figure 17.1 **A,** Fresnel prism is thin because it is really a series of prisms stacked one on top of the other. The concept of individual prisms attached to a thin piece of plastic is shown. **B,** In actuality, the Fresnel prism is molded from one piece of material.

Figure 17.2 A Fresnel lens has a series of slightly visible lines on the surface. These lines are really ledges that indicate the location of the base of the prism. The base direction is at right angles to the direction of the visible lines.

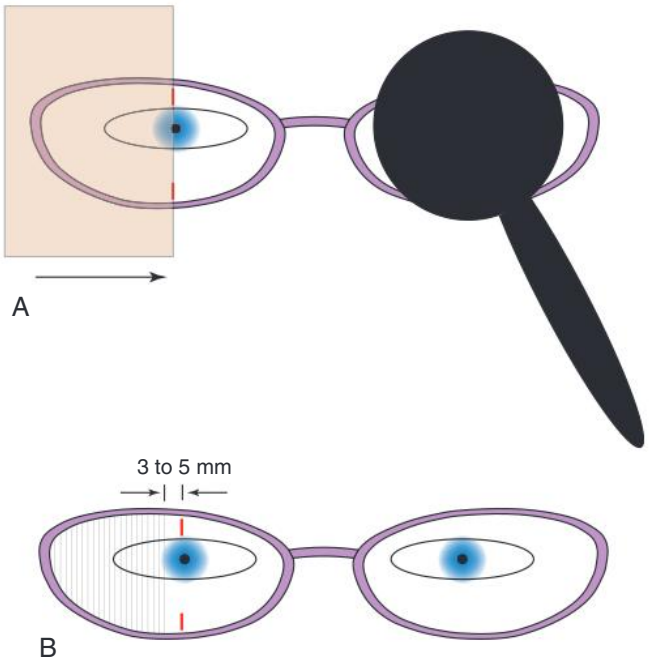


Figure 17.3 **A,** To position a Fresnel prism for homonymous hemianopia using unilateral sector prism, occlude the eye with the nasal field loss. On the eye with the temporal field loss, move the card from the temporal side until the person first sees the card. Mark the position of the card. (Marks are shown in red.) **B,** Measure back the desired amount from this point to find the location of the apical edge of the prism. Apply the prism to the temporal portion of the lens.

as close as 1.5 mm. The amount of prism may vary from approximately 12Δ to 20Δ.[3] Although Fresnel prism may be used for full-time wear, if successfully worn, it is possible to replace it by ordering slab-off prism with the slab line oriented vertically. (The slab-off line is oriented horizontally when used in correcting for vertical imbalance.)

If prism is placed on the same side of both right and left lenses, it is called *yoked sector prism.* For the treatment of homonymous hemianopia, the base direction should be oriented toward the blind side. (Remember *bb: **b**ase **b**lind.*) If the blind side is to the person's right side, the right eye prism is placed base out and the left eye is placed base in. Both are of the same prism power and are placed base right.

If prism is placed on only one lens, it is placed temporally, base out, and on the lens corresponding to the eye on the same side as the vision loss and is called *unilateral sector prism.* Prism on only one lens is often the preferred method since sector prism on both lenses interferes with near working distance tasks, which would cause one of the eyes to be looking through nasal prism.

Disadvantages of Sector Prisms. There are some disadvantages with compensating for homonymous hemianopia using sector prism. When moving the eyes into the prism, there is a sudden change in prismatic effect. This causes the image to change locations or jump. (For more on the type of image jump that occurs with bifocal lenses, see Chapter 19.) Because of this image displacement, there is a section of the visual field that disappears. This missing part of the visual field is toward the apex of the prism and is called an *apical scotoma.* The greater the prism amount, the larger the apical scotoma.

If the prism being used is yoked sector prism, both right and left images jump at the same time and by the same amount. This does not cause double vision but does introduce an apical scotoma.

If the prism is unilateral sector prism on one eye only, then there is image jump and a scotoma for the eye with the sector prism, but there is no image displacement for the other eye. This means that there will be

an area where there are different images for each eye in the same location—in other words, double vision in the central viewing area, which may require some adaptation time for the wearer.

Eli Peli's High-Powered Peripheral Prism

Another method of sectorial application of prism for helping the person with homonymous hemianopia places high-powered (40Δ or 57Δ) prism in peripheral segment areas located above and below the center of the lens.[4] Although this will also cause double vision, these double images are located peripherally and not centrally. This makes adaptation easier.

Using Horizontal Prism Peripherally. In an innovatively unique arrangement, two prism segment areas with their base-apex axis in the horizontal meridian are placed on the lens. The eye chosen is the one on the same side as the visual field loss. In other words, if the right half of the visual field is missing, the segments are placed on the right eye. The upper segment is placed 6 mm above the pupil center, and the lower one 6 mm below the pupil center (Figure 17.4). These prisms, usually 40Δ in power, are placed base out and will create peripheral diplopia in that eye. Objects seen through the segment areas are shifted horizontally from the nonseeing to the seeing part of the visual field. With adaptation, the individual can visualize the parts of the objects viewed through the prism as being in the areas where they are actually located, thus expanding the visual field area by up to 20 degrees[4] (Figure 17.5). This field expansion is of great help in preventing collisions with others when walking through crowded areas such as shopping malls or airport terminals.

When fitting the prism segments, the first trials are done with precut Fresnel prism segments made to the expected dimensions of the finished prism segment areas. After a 4- to 6-week trial period, if the prospects for a successful outcome are good, then the flexible trial Fresnel segments are replaced with Fresnel segments made from hard CR-39 plastic.

The final segments may be worn mounted into the regular prescription lens or mounted in a clip-on or in a slip-over frame. When constructed as a prism segment to be worn directly within the regular spectacle lens, the prism segments are mounted in apertures made in the spectacle lens. Some people will not want to wear the segments all the time. If this is the case, clip-on lenses or slip-over frames are more appropriate. One of the advantages to the clip-ons or slip-overs is that the person wearing them is able to see through both the segments and their prescription lenses instead of only through the prism segment.

Using Oblique Prism Peripherally. Many of those with homonymous hemianopia would like to continue driving. As regulations vary from state to state, whether this is possible will depend on where they live and if they can find a sufficient field expansion solution. With horizontal prisms, the field expansion is above and below the central viewing area. Unfortunately, this is outside the viewing area of the windshield of the car—a major disadvantage when driving. To be able to expand the field of view to include the central area, the 40Δ horizontal prism segments are replaced with 57Δ oblique prisms. The top prism is tilted base downward from the horizontal, and the bottom prism segment is tilted base upward from the horizontal[4] (Figure 17.6). This picks up the central blind area and allows it to be seen through the segments (Figure 17.7). The power of the prism is higher because otherwise the horizontal field expansion would be reduced because the net amount of horizontal prism is reduced as the prism is tilted. The segments themselves look the same and remain horizontal, but the Fresnel base lines within the segment are clearly angled.

Research on improvements continues. At the time of this writing, these designs (and perhaps future evolving versions) are available

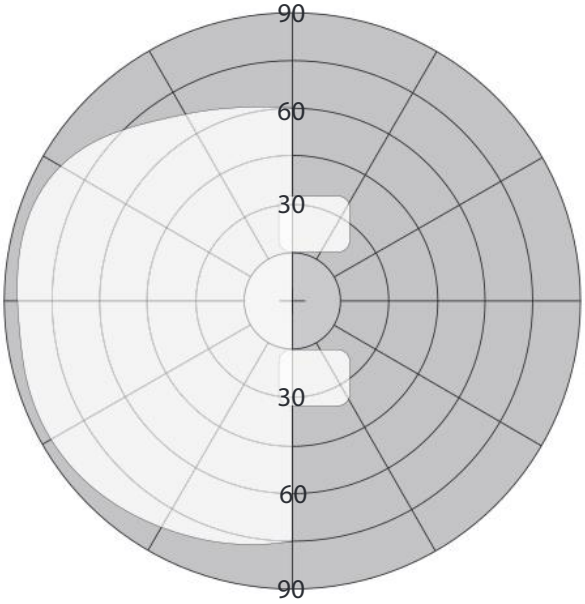


Figure 17.5 This is what a binocular visual field might look like for a person with a right homonymous hemianopia when wearing Peli's horizontal peripheral prism. If you were the person with the defect, the white area would be your seeing area. Without the horizontal sector prisms, the notches of vision would be missing and only the left half of the field would be seen. Keep in mind that objects seen in the notch areas are visible but do not appear in the notch location. Instead, they are superimposed above and below the line of sight in the left (seeing) visual field area.

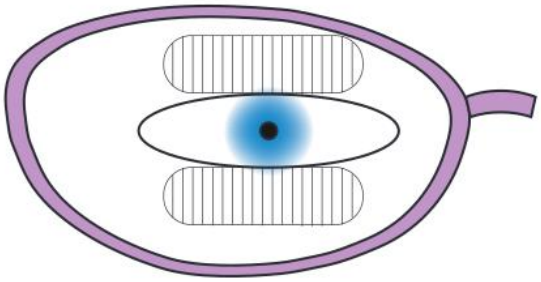


Figure 17.4 These temporary 40Δ base out Fresnel prism segment areas are used to create peripheral diplopia for those who have a homonymous hemianopia visual field loss. They may later be replaced with permanent prism segments, usually also of Fresnel-type construction. These permanent segments are made from hard plastic material and may be mounted within the carrier spectacle lens. As an alternative, they may be mounted on clip-on lenses or on the lenses of a slip-over frame.

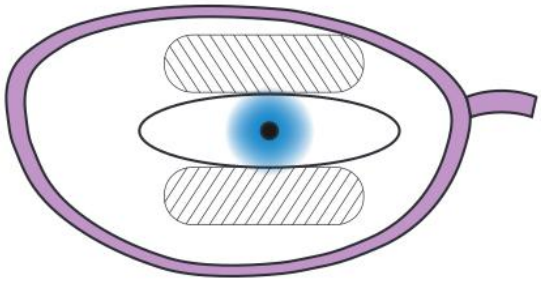


Figure 17.6 This is a representation of 57Δ peripherally placed prism segments with their base directions oriented obliquely. For a right homonymous hemianopia, the prisms are placed on the right lens. The top prism is oriented base out and down; the bottom, base out and up. Objects in the right central area of the visual field will be prismatically shifted to locations above and below the line of sight in the left (seeing) area of the visual field.

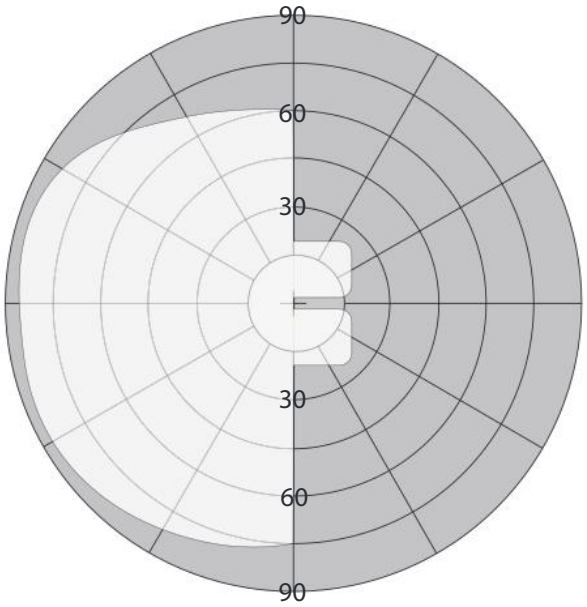


Figure 17.7 This is what a binocular visual field might look like for a person with a right homonymous hemianopia when wearing obliquely oriented 57Δ Peli's peripheral prisms as seen in Figure 17.6. If you were the person with the defect, the white area would be your seeing area. The viewing areas seen through the prisms are shifted closer to the horizontal, bringing them into the viewing area of the windshield. Again the objects seen in the notch areas are visible but do not appear in the notch location. Instead they are superimposed above and below the line of sight in the left (seeing) visual field area. So the visual field diagram can be confusing, since the notches do not appear where they seem to be located. They only indicate what can be seen in this area of the visual field. To the one with the defect, these areas appear above and below on the left side.

through Chadwick Optical, an optical laboratory specializing in supplying low-vision corrections.

Cosmetics of Nonseeing Eyes

In Chapter 21 of this text, the use of prism to improve the appearance of a blind or prosthetic eye is discussed. Fresnel prisms may be used in such instances.

Slowing of Nystagmus

Nystagmus is a fixation disorder characterized by a constant back and forth movement of the eyes. Such movement is involuntary and reduces vision. In some cases, nystagmus may slow when the person looks to one side or the other. For example, if the examiner sees that movement slows when the person looks to the right, equal amounts of prism may be applied to both lenses. The correct base direction for these two yoked prisms would be base left. Because the eyes turn toward the apex, placing prism base left will keep the head pointed straight while the eyes turn to the right. Since the eyes are turned to the right, nystagmus slows.

For a summary of Fresnel prism uses, see Table 17.1.

TABLE 17.1 Clinical Applications for Fresnel Prisms

Uses	Comments
High prism amounts	These keep the lens thin.
Temporary prism	The practitioner can get an idea of how prism will work before ordering. It is possible to change prism amount without remaking the glasses.
Sectorial application of prism for palsied muscle	Prism can be applied to half or any portion of the lens.
Visual field defects such as homonymous hemianopia	Use yoked or unilateral prism applied sectorially in the nonseeing area. Use for Peli's peripheral prism. (Orient the prism base toward the blind side.)
Prism in bifocal areas only	Prism can be horizontal and/or vertical.
Cosmetic improvement of blind, turning eye	Use inverse prism (e.g., if the eye turns out, give base out prism) (see Chapter 21).
Treatment of nystagmus	Use yoked prism to reduce involuntary pendular eye movement (e.g., both base left or both base right).
For those who cannot sit up in bed	Use yoked base-down prism of 15Δ to 30Δ. (Note: There are also "recumbent spectacles" that are specially made for these purposes. See Appendix B.)
Use as a partial occluder	Place prescribed Fresnel prism over the nonamblyopic eye. When treating amblyopia, Fresnel prism will slightly "penalize," or decrease visual acuity in the better eye and serve as a partial occluder. The idea is to cause the weaker amblyopic eye to improve.

WHAT IS A FRESNEL LENS?

Chapter 12 explains how a lens works. Figure 12.20 presents the concept of how a plus lens is like a series of prisms, each more powerful than the one before. The front and back surfaces at the optical center (OC) of a lens are flat, but as the distance from the OC increases, the lens surfaces become more angled.

A Fresnel lens is similar to a series of concentric prisms, each with a slightly higher prismatic effect (Figure 17.8). When the concentric surfaces are angled correctly, a plus or minus sphere of any desired power may be created. Advantages and disadvantages of Fresnel lenses parallel those of Fresnel prisms. (At the time of this writing, Fresnel minus lenses for ophthalmic use are being discontinued.)

Nonspectacle Uses

Fresnel lenses are not just used for spectacles. Historically, they have been used in old railroad lanterns and to project the warning beams of seaside lighthouses. More recently, they have been used in virtual reality headsets to decrease the weight and price of the units.

When Are Fresnel Lenses Used?

Short-Term Wear

Clinically, Fresnel lenses are useful on a temporary basis, such as during vision therapy or with frequent changes in refraction.

Creating Adds

Fresnel lenses can also be applied to one portion of the spectacle lens. High add powers can be created for low-vision or occupational purposes.

Figure 17.8 The Fresnel lens shown here is in the original container but has been turned around so that the rings will be more apparent. When worn, the rings will be much less visible than their appearance in the photograph because they will be on the back surface of the Fresnel lens, and the Fresnel lens will be on the back surface of the carrier spectacle lens.

TABLE 17.2 Clinical Applications for Fresnel Lenses

Use	Comments
To create a thin lens	Fresnel lenses are always thin, regardless of lens power.
As temporary lenses	Fresnel lenses can be especially handy during vision therapy or when lens powers may need to be changed frequently.
With underwater diving masks, swimming goggles, etc.	Application to optical surfaces is easy.
For sectorial applications	Plus lenses of normal or high powers can be used as a multifocal add; this add can be used temporarily (or permanently for certain unusual occupational needs) or for low vision.
As trial bifocals	Applications are available in powers from +1.00 to +6.00 D. Application is used for accurate determination of bifocal height, for temporary wear, or for making sunglasses into multifocals.

Fresnel lenses are available as precut bifocal segments in powers ranging from +1.00 to +6.00 D. These segments will also work well in the dispensary to give a realistic simulation of bifocal heights (see Chapter 5, Figure 5.21).

Fresnel lenses or lens segments can be used to create special occupational lenses. For example, if a person has a need for a double D occupational lens, the current bifocal or progressive add lens can be converted to an occupational lens using an upside-down Fresnel bifocal segment at the top. If Fresnel segments are placed on a pair of single-vision sunglasses, it changes them into prescription bifocal lenses.

For a summary of Fresnel lens uses, see Table 17.2.

How Should a Fresnel Lens or Prism Be Applied to a Spectacle Lens?

Fresnel prisms and lenses are applied using the following steps:

1. For lenses, mark the desired position of the lens OC on the *front* of the carrier lens. (The carrier lens is the spectacle lens already in the eyeglass frame.)

   For prisms, determine correct base direction. In the presence of horizontal and vertical prism, determine what single prism amount and base direction will result from the combination of the two prisms. This may be done by direct calculation as described in Chapter 15 or by using a Prism Rotation Nomogram available from suppliers of Fresnel prisms.
2. Take the carrier lens out of the spectacle frame.
3. Place the Fresnel lens or prism on the *back* of the carrier lens with its smooth side against the carrier. Be sure the OC or base direction is properly oriented.
4. With a razor blade, trim the Fresnel lens or prism flush with the beveled edge of the carrier lens. (It is also possible to use sharp, high-quality scissors.)
5. Remove the Fresnel lens or prism, and reinsert the carrier lens into the frame.
6. Wash both carrier and Fresnel lens with a weak solution of lotion-free, liquid detergent.
7. In a bowl of warm water or under a stream of warm water, apply the smooth side of the Fresnel to the carrier. Work out any air bubbles that may be trapped between the two surfaces.
8. Give the lenses to the wearer, but instruct the wearer to handle with care for 24 hours until drying is complete.

It is possible to substitute rubbing alcohol for water when applying Fresnel lenses and prisms. The lens is said to adhere more quickly, the bubbles slide out more easily, evaporation is faster, and the lens can be dispensed sooner without fear that the Fresnel prism might slide out of place.[5]

How Should Fresnel Lenses or Prisms Be Cleaned?

The manufacturer's recommended method of cleaning these lenses is to rinse them under warm running water. If the lenses have dirt in the grooves, use a soft brush. Blot dry with a soft, lint-free cloth. Hard contact lens cleaning solutions have also been used to clean Fresnel optics.

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PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. If a Fresnel prism is to be placed base out, will the visible lines on the lens be horizontally or vertically oriented?
   a. horizontally
   b. vertically
2. To mount a Fresnel prism at a prism base direction of 45 degrees, the visible lines on the Fresnel prism should end up being orientated
   a. parallel to the 45 degree prism base direction.
   b. perpendicular to the 45 degree prism base direction.
   c. neither way, since the line pattern is circular.
   d. neither way, because there are no visible lines.
3. True or false? Visual acuity is better with Fresnel prisms than with conventional prisms.
   a. True
   b. False
4. True or false? When high-powered Fresnel prism is added to a regular refractive-powered carrier lens, there is a decrease in visual acuity, but when high-powered conventional prism is ground into a regular refractive-powered lens, there is no decrease in visual acuity.
   a. True
   b. False
5. Which of the following statements is true?
   a. A Fresnel prism is reusable but not a Fresnel lens.
   b. A Fresnel lens is reusable but not a Fresnel prism.
   c. Both are reusable.
   d. Neither are reusable.
6. For those with homonymous field defects, an "increase" in field (or at least an increase in the ability to quickly view more of the blind field area) is achieved by placing Fresnel prism (or horizontal slab-off prism) on the spectacles in the defect area. If this is done, the base direction should be
   a. toward the side or direction of the defect.
   b. away from the side or direction of the defect.
7. A disadvantage of using unilateral sector prism applied to the non-seeing side of the lens for the eye with the nasal field loss for homonymous hemianopia is that it may create
   a. an apical scotoma.
   b. diplopia (double vision) in the central viewing area.
   c. peripheral diplopia.
   d. all three of the above effects, which are disadvantages to using unilateral sector prism.
   e. both an apical scotoma and diplopia in the central viewing area, which are disadvantages.
8. The primary reason for using peripherally placed oblique prism instead of just horizontal prism is to
   a. expand the visual field farther into the nonseeing area.
   b. allow the wearer to see what is in the central section of the nonseeing area.
   c. expand the visual field in the nonseeing area vertically.
9. Suppose that prism is to be used to slow nystagmus. If the nystagmus slows when the individual turns the head to the left while still looking straight ahead, the prism should be applied
   a. base to wearer's right for the left eye and base to the wearer's left for the right eye.
   b. base to the wearer's left for the left eye and base to the wearer's right for the right eye.
   c. base to the wearer's right for both right and left eyes.
   d. base to the wearer's left for both right and left eyes.
   e. This type of prism use for slowing nystagmus is not feasible.
10. Fresnel prisms and lenses are applied
    a. to the back of the spectacle lens with the smooth side away from the lens.
    b. to the front of the spectacle lens with the smooth side away from the lens.
    c. to the back of the spectacle lens with the smooth side toward the lens.
    d. to the front of the spectacle lens with the smooth side toward the lens.
11. A Fresnel prism is physically applied to the spectacle carrier lens by
    a. using a hard contact lens cleaning solution between carrier and Fresnel lenses.
    b. applying a removable adhesive between carrier and Fresnel lenses.
    c. using running water between carrier and Fresnel lenses.
    d. using Fresnel Lens-Lok between carrier and Fresnel lenses.
    e. peeling the back off the prism and applying the self-adhesive Fresnel lens to the carrier lens.

18

Lens Design

A SHORT HISTORY OF LENS DEVELOPMENT

Lenses have gone through several stages of development. To quickly summarize, here are some general categories and time lines.[1] These describe not the theoretical development of the lens but when these lenses were introduced and available.

1. *"Flat" lenses* (1200 to 1800): Actually the word "flat" is deceiving, since neither side of the lens was flat. Instead, the lens was bean shaped, like a lentil—the bean that resembles the shape of a lens. The lenses worked well for central vision, but vision was poor through the edges.
2. *Periscopic lenses* (1800s): An improvement in peripheral vision occurred when a −1.25 D back surface was used.
3. *Six-base meniscus lenses* (Beginning in the 1890s): These lenses improved vision in several ways. The quality of peripheral vision increased markedly. The lenses could also be fit closer to the eye because the vault of the lens cleared the lashes. Six-base lenses were still used up until the 1960s. During the 1950s and 1960s the use of six-base lenses moved almost entirely to places that were known for low-end pricing. Eventually, companies simply stopped producing these types of lenses.[2]
4. *Corrected curve lenses* (early 1900s): In 1908 the Carl Zeiss Company introduced Punktal lenses that corrected for oblique astigmatism found in the lens periphery. These lenses required a very large number of base curves and became available in the United States in 1913. In 1919 American Optical (AO) introduced a corrected curve series of lenses that also corrected for oblique astigmatism, but, unlike the earlier Punktal lenses with a large number of required base curves, the AO lenses were designed with base curves that changed in one or two diopter intervals. This made stocking semifinished lenses much more practical. In the 1960s there was a transition time while single-vision lenses were being converted from plus cylinder form (with the toric surface on the front) to minus cylinder form to match the back surface torics that were already being used for multifocal lenses.
5. *Aspheric lenses*: Aspheric lenses have been available for very high plus "cataract" style corrections beginning in the early part of the 20th century. They have been available in lower powered plus and minus single-vision lens form since the latter part of the 20th century but only began to enjoy more widespread use as higher index plastic lens materials became available.
6. *Atoric lenses*: Atoric lenses are replacing the aspheric lens series in single-vision finished lenses. Atoric lenses are available in multifocal lenses only when requested and are produced using free-form lens surfacing. They are available in higher end progressive lenses using free-form surfacing.
7. *Position of Wear*: Positions of wear lenses are those that take fitting variables into consideration. Changes from the position of the lens during refraction compared with the position of the lens when being worn will cause the lens to have a power different from what was intended. Changes will include such things as vertex distance, pantoscopic tilt, and frame wrap-around. Changes to the prescribed power are made to compensate for how the lenses are worn so that they maintain the originally desired refractive outcome. Free-form surfacing makes it possible to produce these lenses more accurately.

LENS ABERRATIONS

To understand the developments and characteristics of lens designs, it is necessary to understand what problems the designer is attempting to prevent. Such problems, which cause lenses to deliver less than a perfect image, are known as *aberrations*.

When light from a point source goes through a correctly powered spectacle lens yet fails to create a perfect image, the cause is lens aberration. There are several types of lens aberrations that can contribute to an imperfect image. These aberrations can be grouped into two major types: *chromatic aberration* and *monochromatic aberration*.

Chromatic aberration is color-related. It may cause an image to have a colored fringe. Monochromatic aberration occurs even when the light source contains only one wavelength (one color).

Chromatic Aberration

There are two manifestations of chromatic aberration. One is called *longitudinal chromatic aberration*. Longitudinal chromatic aberration occurs when a point light source that is composed of several wavelengths (e.g., white light) forms a series of point images along the optical axis. Each of these images is of a different color, and each has a slightly different focal length.

The second manifestation of chromatic aberration is called *lateral chromatic aberration*. This type of chromatic aberration will produce images of slightly different sizes at the focal length of the lens, depending on the color of the light.

Longitudinal (Axial) Chromatic Aberration

Since each color, or wavelength, undergoes a slightly different degree of refraction at the same surface curvature, longitudinal chromatic aberration results in a series of foci spread out along the optic axis (Figure 18.1). Thus, longitudinal chromatic aberration can be expressed as the dioptric difference between two extremes—blue light (F_F) and red light (F_C). Written as a formula,

$$\text{longitudinal chromatic aberration} = F_F - F_C$$

Longitudinal chromatic aberration is not directly related to prismatic effect. Therefore, plano prisms do not have longitudinal chromatic aberration.

Normally, we think of glass or plastic lens material as having one specific index of refraction (n). In actuality, lens material has a slightly different index of refraction for each wavelength. The index of refraction we memorize for a given lens material is really the index of refraction for yellow light. Lens materials that are relatively free of chromatic aberration have indices of refraction that are nearly the same for each wavelength.

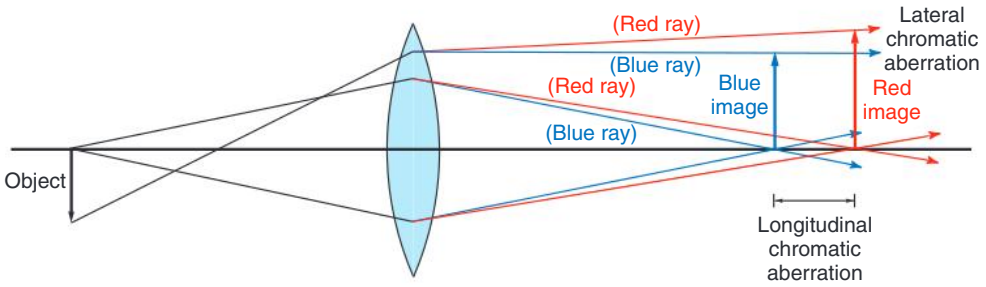


Figure 18.1 Chromatic aberration has two aspects. One is longitudinal chromatic aberration. This means that light of different wavelengths will focus at different focal distances from the lens. The other aspect is lateral chromatic aberration. Lateral chromatic aberration is shown here and in Figure 18.2.

Materials that have a lot of chromatic aberration, such as the glass for crystal chandeliers, have indices of refraction that span a larger range.

Longitudinal chromatic aberration can be written another way. To find out how, we start with the Lensmaker's formula:

$$F = (n-1)R$$

where

F = the power of the lens,
n = the refractive index of the lens (for yellow light), and
R = the *Curvature* of the lens.

(Note: *Curvature* (R) is the reciprocal of the *radius of curvature* in meters. Radius of curvature is abbreviated using the lower case r. In other words, $R = \frac{1}{r}$. It should also be noted that $R = R_1 - R_2$, where R_1 = the curvature of the first lens surface and R_2 = the curvature of the second lens surface.)

Since

$$\text{Longitudinal chromatic aberration} = F_F - F_C,$$

longitudinal chromatic aberration can also be expressed as

$$\begin{aligned}\text{Longitudinal chromatic aberration} &= (n_F - 1)R - (n_C - 1)R \\ &= (n_F - 1 - n_C + 1)R \\ &= (n_F - n_C)R.\end{aligned}$$

The quantity $(n_F - n_C)$ helps to define the chromatic nature of the material and is called *mean dispersion*.

Since lens power is specified in terms of yellow light, F can also be more specifically written as F_D.

If

$$F = (n-1)R,$$

then

$$F_D = (n_D - 1)R.$$

This last equation can be transposed and written as

$$R = \frac{F_D}{n_{D-1}}.$$

Because

$$\text{Longitudinal chromatic aberration} = (n_F - n_C)R$$

longitudinal chromatic aberration may also be written as

$$\text{Longitudinal chromatic aberration} = (n_F - n_C)\frac{F_D}{n_D - 1}$$

or as

$$\text{Longitudinal chromatic aberration} = \left(\frac{n_F - n_C}{n_D - 1}\right)F_D.$$

This part of the equation—

$$\left(\frac{n_F - n_C}{n_D - 1}\right)$$

is useful for quantifying chromatic aberration for a given material. It is called the *dispersive power*. Dispersive power is abbreviated as the Greek letter omega (ω). This means that the longitudinal chromatic aberration formula can be written in a more abbreviated form as

$$\text{Longitudinal chromatic aberration} = \omega F_D.$$

The Abbé Value

Because the value for dispersive power ends up as a decimal value, working with it can be unwieldy. It is easier to work with its reciprocal value. The reciprocal of dispersive power comes out as a whole number. The reciprocal of ω (dispersive power) is symbolized by the Greek letter nu (ν). In other words,

$$\frac{1}{\omega} = \nu$$

This value (ν) has three different names. It is called the *nu*, the *constringence*, or the *Abbé value*.

The *Abbé value* is the most commonly used name for identifying the amount of chromatic aberration for a given lens material. The higher the Abbé value is, the less chromatic aberration is present in the lens. The lower the Abbé value is, the more likely it will be that color fringes will be seen through the lens and that visual acuity will be reduced when looking through the periphery of high-powered lenses. Table 18.1 shows Abbé values and refractive indices for some representative ophthalmic materials.

TABLE 18.1 Abbé Values for Some Representative Lens Materials

Lens Material	Refractive Index	Abbé Value
Crown Glass	1.523	58
CR-39 plastic	1.498	58
Corning Photogray Extra (glass)	1.523	57
Trivex (plastic)	1.532	43–45
Spectralite (plastic)	1.537	47
Corning 1.6 index PGX (glass)	1.600	42
Essilor Thin-n-Lite (plastic)	1.740	33
Essilor Stylis (plastic)	1.670	32
Schott High-Lite Glass	1.701	31
Polycarbonate	1.586	30

Using the Abbé value means that longitudinal chromatic aberration is most usefully written as

$$\text{Longitudinal chromatic aberration} = \frac{F}{\nu}.$$

Generally speaking, longitudinal chromatic aberration in spectacle lenses worn for everyday purposes is not thought to have a significant effect on vision. This is because the longitudinal chromatic aberration of the eye is enough higher than that of the spectacle lens so that the effect is considered to be negligible.

Example 18.1

We are interested in knowing how longitudinal chromatic aberration compares between two +6.00 D lenses when one is made from polycarbonate and the other from CR-39 plastic. Find the longitudinal chromatic aberration for this lens power in both CR-39 plastic and polycarbonate.

Solution

Longitudinal chromatic aberration can be found by dividing the power of the lens by the Abbé value of the material from which the lens is made. Polycarbonate has an Abbé value of 30, and CR-39 an Abbé value of 58. Beginning with polycarbonate we find:

$$\begin{aligned}\text{Longitudinal chromatic aberration}_{(polycarb)} &= \frac{F}{\nu}\\ &= \frac{6}{30}\\ &= 0.20\,\text{D}\end{aligned}$$

CR-39 plastic has a longitudinal chromatic aberration of:

$$\begin{aligned}\text{Longitudinal chromatic aberration}_{(CR-39)} &= \frac{F}{\nu}\\ &= \frac{6}{58}\\ &= 0.10\,\text{D}\end{aligned}$$

Lateral (or Transverse) Chromatic Aberration and "Chromatic Power"

Lateral chromatic aberration is expressed either as differences in image magnification or differences in prismatic effect.

Magnification differences. With refractive lenses, lateral chromatic aberration is thought of in terms of *magnification differences*. A magnification difference is the difference in size between the images formed by two different wavelengths, such as red and blue (see Figure 18.1).

Differences in prismatic effect. When quantified by prismatic effect, the lateral chromatic aberration of a prism is the difference in prismatic effect for light of two different wavelengths (Figure 18.2). As a formula this would be expressed as

$$\begin{aligned}\text{Lateral chromatic aberration} &= (\text{Prismatic effect for blue light})\\ &\quad -(\text{Prismatic effect for red light})\end{aligned}$$

or

$$\text{Lateral chromatic aberration} = \Delta_{blue} - \Delta_{red}$$

Lenses have prismatic effects as well. But for a lens, the prismatic effect will depend on the power of the lens and the distance from the optical center (OC) of the lens. We know that prismatic effect increases as we look farther away from the center of the lens. Prismatic effect for a given point on a lens is determined by Prentice's rule. Prentice's rule states

$$\Delta = cF$$

where c is the distance from the OC in centimeters, and F is the dioptric power of the lens. Sometimes the letter d (for distance in centimeters) is used instead of c (for centimeters). This is traditionally the case when working with lateral chromatic aberration, so we will use it that way here. Therefore, since

$$\Delta_{blue} = dF_F \text{ and } \Delta_{red} = dF_C$$

and

$$\text{Lateral chromatic aberration} = \Delta_{blue} - \Delta_{red},$$

then

$$\begin{aligned}\text{Lateral chromatic aberration} &= dF_F - dF_C\\ &= d(F_F - F_C).\end{aligned}$$

For longitudinal chromatic aberration, both the formulas

$$\text{Longitudinal chromatic aberration} = F_F - F_C$$

and

$$\text{Longitudinal chromatic aberration} = \frac{F}{\nu}$$

are useable and equal to one another. Therefore, we know that

$$F_F - F_C = \frac{F}{\nu}.$$

If both sides of the equation are multiplied by d (decentration), we see that

$$d(F_F - F_C) = d\frac{F}{\nu}.$$

Looking at the left-hand term in the equation, we recognize the formula for lateral chromatic aberration. This means that lateral chromatic aberration can also be written as

$$\begin{aligned}\text{Lateral chromatic aberration} &= d\frac{F}{\nu}\\ &= \frac{\text{Prismatic effect}}{\nu}\\ &= \frac{\Delta}{\nu}.\end{aligned}$$

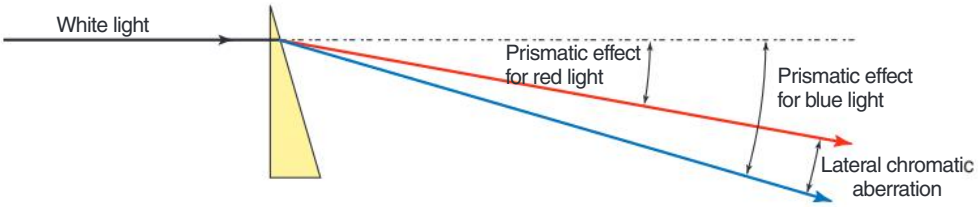


Figure 18.2 Lateral chromatic aberration occurs when a prism bends light of two different wavelengths by different amounts.

(Notice that dF is the same as the *cF* in Prentice's rule, which states that $\Delta = cF$.)

Since ν is the Abbé value, it is now possible to find lateral chromatic aberration quickly if the Abbé value of a lens is known.

When lateral chromatic aberration refers to differences in prismatic effect, as shown previously, it is sometimes called *chromatic power*.

The concept of chromatic power allows us to see that, as prismatic effect increases, the effects of chromatic aberration become more powerful and, hence, more disturbing to vision.

Example 18.2

In the previous example, we found the longitudinal chromatic aberration for a +6.00 D lens. Lateral chromatic aberration is a function of prismatic effect. We can find the lateral chromatic aberration for a prism of a certain material. But we cannot simply ask "What is the lateral chromatic aberration for a +6.00 D lens of a certain material." However, we can ask (and are asking) the following question. "What is the lateral chromatic aberration for a point 15 mm below the optical center of a +6.00 D lens when it is, (A) made from polycarbonate material, and (B) made from CR-39 plastic?"

Solution

For a prism, lateral chromatic aberration is the prism amount (Δ) divided by the Abbé value (ν).

$$\text{Lateral chromatic aberration} = \frac{\Delta}{\nu}$$

For a certain point on a lens, to find the lateral chromatic aberration, we need to know the prismatic effect at that particular point. For a lens with power, the prismatic effect is the power of the lens times the distance of the decentered point from the optical center, or $\Delta = dF$. This makes the lateral chromatic aberration equal to:

$$\text{Lateral chromatic aberration} = \frac{dF}{\nu}$$

For a point 15 mm below the center of a polycarbonate lens, the lateral chromatic aberration is:

$$\text{Lateral chormatic aberration}_{(polycarbonate)} = \frac{(1.5)(6)}{30} = 0.30\Delta$$

For the same point on a CR-39 lens, the lateral chromatic aberration is:

$$\text{Lateral chormatic aberration}_{(CR-39)} = \frac{(1.5)(6)}{58} = 0.16\Delta$$

When does lateral chromatic aberration reduce visual acuity? Suppose a person is wearing a pair of prescription spectacle lenses and is looking at an object directly through the OCs. When the wearer looks through the OCs, there is no prismatic effect and, thus, no chromatic power.

As the wearer looks to the right or left, the prismatic effect of the lenses increases and so does the chromatic power. The more the chromatic power (lateral chromatic aberration) increases, the more the image blurs. There is more prismatic effect in the periphery of a high-powered lens than in the periphery of a low-powered one. So, peripheral visual acuity drops off faster for high-powered lenses than it does for low-powered ones.

The higher the lateral chromatic aberration is, the lower the Abbé value will be. The lower the Abbé value is, the faster the reduction in relative visual acuity will be peripherally. (This is shown in Figure 18.3.)[3]

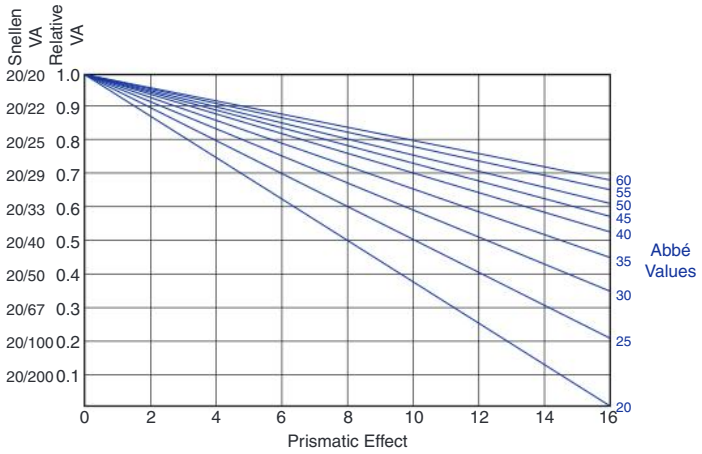


Figure 18.3 The effect of lateral chromatic aberration on visual acuity (*VA*) may be quantified by prismatic effect and Abbé value. In the graph, Abbé value is shown on the right. The graph portrays what happens to visual acuity as prism amount increases and Abbé value decreases. The lower the Abbé value is, the greater the lateral chromatic aberration. The greater the lateral chromatic aberration is, the more visual acuity will decrease for equal prism amounts. Wearers with high amounts of prescribed prism will be less tolerant of lenses made from low Abbé-value material than wearers of prescriptions having an equal refractive power but with no prescribed prism. Even without prescribed prism, prismatic effect increases toward the periphery of a strongly powered lens. The amount of prism may be calculated using Prentice's rule. This graph shows how visual acuity can drop when viewing objects through the periphery of the lens as prismatic effect increases. For reference, polycarbonate has an Abbé value close to 30 and CR-39 plastic between 58 and 60. (Redrawn from Meslin D, Obrecht G: Effect of chromatic dispersion of a lens on visual acuity, Am J of Optom Physiol Opt 65:25–28, 1988. Figure 2, The American Academy of Optometry, 1988.)

Fortunately, the peripheral areas of a lens are seldom used for intensive viewing during normal spectacle lens wear. Instead, if something needs to be seen clearly, the head is turned. Otherwise, lens materials with low Abbé values would not be as well tolerated as they are.

To reduce the possibility of chromatic aberration becoming troublesome, pay attention to the dispensing factors shown in Box 18.1.

How does prism alone affect visual acuity? The previous section talks about how visual acuity is affected by the increasing prismatic effects through the periphery of powered spectacle lenses. The reason for this is prism power alone. So just as visual acuity predictably drops in the periphery of dioptrically powered spectacle lenses, it just as predictably drops with plano prism lenses. (If a lens has no refractive dioptric power but only prism power, it would be called a *plano prism*.) The graph in Figure 18.3 shows how prism by itself can lower visual acuity. How much acuity is lowered depends upon the power of the prism and the Abbé value of the lens material. So, lateral chromatic aberration can reduce visual acuity even when the wearer looks through the center of a lens with prescribed prism with or without refractive dioptric power.

Example 18.3

What is the expected visual acuity when looking through a point 12 mm temporal to the distance optical center of a −8.00 D CR-39 lens with an Abbé value of 58? How would this compare with a polycarbonate lens having an Abbé value of 30 when looking through this same temporal point?

Solution

To find the answer to this question, first use Prentice's rule to find prismatic effect. Prismatic effect is

$$\begin{aligned}\Delta &= cF\\ &= (1.2)(8)\\ &= 9.6\end{aligned}$$

Next we look up visual acuity in Figure 18.3. Looking up a prismatic effect of 9.6Δ for a 58 Abbé-value material shows a relative visual acuity of 0.8. (Relative visual acuity is simply Snellen expressed as a decimal number instead of a fraction. For example, a Snellen VA of 20/40 would be a relative visual acuity of 0.5.) A relative visual acuity of 0.8 is equal to a Snellen visual acuity of 20/25.

If we look up the expected visual acuity at this same temporal point for a polycarbonate lens with an Abbé value of 30, we find a relative visual acuity of 0.6. This is the same as a Snellen visual acuity of 20/33.

BOX 18.1 Important Dispensing Factors for Lenses With Low Abbé Values (Polycarbonate and Some High-Index Materials)

1. Use monocular interpupillary distances.
2. Measure major reference point heights, considering pantoscopic angle (see Chapter 5).
3. Have sufficient pantoscopic angle but not more than 10 degrees for high lens powers.
4. Use shorter vertex distances.
5. Adhere to the manufacturer's recommendations for correctly chosen base curves. (The same factors that affect oblique astigmatism also influence lateral, or transverse, chromatic aberration.)

Does an Antireflection Coating Reduce Chromatic Aberration?

A common misconception is that using an antireflection (AR) coating will reduce chromatic aberration. It does not. However, an AR coating is often used when there is concern about chromatic aberration. Why might this be? The reason is because both chromatic aberration and lens reflections can be bothersome to the wearer. If only one of these problems is present, the wearer may be able to more easily cope with just one. Thus, an AR coating may appear to be reducing chromatic aberration when it is really just reducing lens reflection problems.

Achromatic Lenses

A lens would be considered totally without chromatic aberration if all of the wavelengths across the visible spectrum focused at one point. This does not happen with ophthalmic lens materials. To create a lens that is considered achromatic, a plus lens of one material is used in combination with a minus lens of another material. The two lens powers must add up to the needed lens power, and light from the *F* (blue) and C (red) spectral lines must focus at the focal point of the lens. Such a lens is called an *achromatic lens* or a *doublet* (Figure 18.4). Achromatic doublets are not used for ordinary spectacle lens wear but rather are used for high-end scientific equipment.

The Monochromatic Aberrations

Aberrations can occur in a lens even when the light entering the lens is only one color. These aberrations, called *monochromatic aberrations*, may be more troublesome for cameras or optical systems than for prescription ophthalmic lenses but are still of definite concern when designing a spectacle lens and evaluating visual performance.

Seidel Aberrations

When rays of light pass through a lens, we expect them to focus at one predictable location. When those rays are paraxial (or central) rays, we can predict the location of focus using the fundamental paraxial equation

$$F = L' - L$$

which, written another way is

$$L' = L + F.$$

The fundamental paraxial equation is derived from Snell's law on the basis of an assumption. The assumption is that, for small angles (measured in radians instead of degrees), $\sin\theta = \theta$. However, a still more accurate approximation for $\sin\theta$ is a polynomial series expansion given as

$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \ldots$$

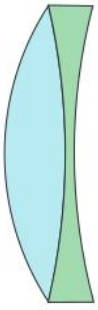


Figure 18.4 An achromatic lens is constructed from two different materials, each with a different refractive index chosen to counteract the effects of chromatic aberration. Achromatic lenses are not used in normal spectacle lenses.

The first term represents the paraxial approximation $\sin\theta = \theta$. If we use both the first and second terms of this equation, we are using third-order terms for $\sin\theta$. In other words, instead of saying $\sin\theta = \theta$, we say that $\sin\theta = \theta - \frac{\theta^3}{3!}$ (again, measured in radians instead of degrees). This substitution gives us the next higher order of approximation. This third-order approximation is used as a basis of comparison when determining the quality of how well a given wave front of light is able to come to a proper focus after passing through a lens, a lens surface, or a lens system. In the process of passing through a lens, the wave front may lose some of its spherical shape. This reveals aberration and a resulting imperfect focus.

Using third-order terms, Seidel classified aberrations into five categories. The five are interrelated. Making a lens change to reduce the amount of one aberration can affect the magnitude of other aberrations. These five aberrations have become known as the *Seidel*, or *third-order*, *aberrations*. (There are other aberrations that will occur when using higher order approximations such as fifth or seventh order.) The five Seidel aberrations are *spherical aberration, coma, oblique (radial or marginal) astigmatism, curvature of field (power error)*, and *distortion*. These will be described shortly.

One of the drawbacks of expressing aberration as Seidel aberrations is that all lens surfaces are assumed to be spherical. To better describe aberration for surfaces that may not be spherical, such as the refracting surfaces of the eye, a different system works better.

Classifying Aberrations Using Zernike Polynomials

There are other systems for classifying how a given wave front deviates from a perfect sphere when leaving a refracting surface, a lens, or a refracting system. One system that describes aberrations of the human eye uses Zernike polynomials. The use of Zernike polynomials is a more complete representation of the aberrations that could be present in a lens or eye. Furthermore, it does not assume spherical surfaces, which Seidel aberrations do. The Zernike system has gained visibility because of an ever-increasing interest in aberrations within the human eye. This interest is driven by several factors, including:

1. *A desire to see into the eye clearly to detect disease-driven changes.* The aberrations of the eye degrade the view of retinal elements within the eye. Correcting these aberrations allows earlier diagnosis of ocular disease.
2. *The challenge of refractive surgery.* Unfortunately, aberrations of the eye are often increased because of refractive surgery. Ideally one would want to not only correct sphere and cylinder refractive errors but also reduce other aberrations to enhance visual performance.
3. *A desire to measure ocular aberrations so that they might be corrected.* If ocular aberrations can be measured, the next logical step is to figure out a way to correct them. Options will include not only refractive surgery but also contact lenses or other methods.

As stated earlier, the use of Zernike polynomials has become a popular system to describe and measure ocular monochromatic aberrations. Zernike polynomials use a numbered term that describes a geometric shape for the aberration. These terms are grouped into orders. (These orders are not the same as those described in the previous section on Seidel aberrations, although some Zernike terms are similar to certain Seidel terms.) Here is how the Zernike orders describe some of the commonly known aberrations related to the eye.[4]

Order	***Aberration***
1st	Prism
2nd	Defocus and astigmatism (Defocus includes spherical refractive error such as myopia and hyperopia)
3rd	Coma and trefoil
4th	Spherical aberration and other modes
5th to 10th	Higher order irregular aberrations

According to the orders within this classification, second-order aberrations of the eye include myopia, hyperopia, and astigmatism. These aberrations are corrected using sphere and cylinder lenses. Those aberrations classified as third-order and above are referred to as *higher order aberrations*.

The Five Seidel Aberrations

Spherical Aberration

Spherical aberration is a Seidel aberration that occurs when parallel light from an object enters a large area of a spherical lens surface (Figure 18.5). When spherical aberration is present, peripheral rays focus at different points on the optic axis than do paraxial rays. (Peripheral rays are those that enter the lens nearer the edge than the center. Paraxial rays are those that pass through the central area of the lens.)

Spherical aberration occurs when the object point is on the optical axis of the system. All of the other Seidel aberrations occur when the object point is off the optic axis.

Because the pupil of the eye limits the number of rays entering the eye for any given direction of gaze, spherical aberration is not a large problem in ophthalmic lenses.

Coma

The second Seidel aberration is coma. When the object point is off the axis of the lens, there is a difference in magnification for rays passing

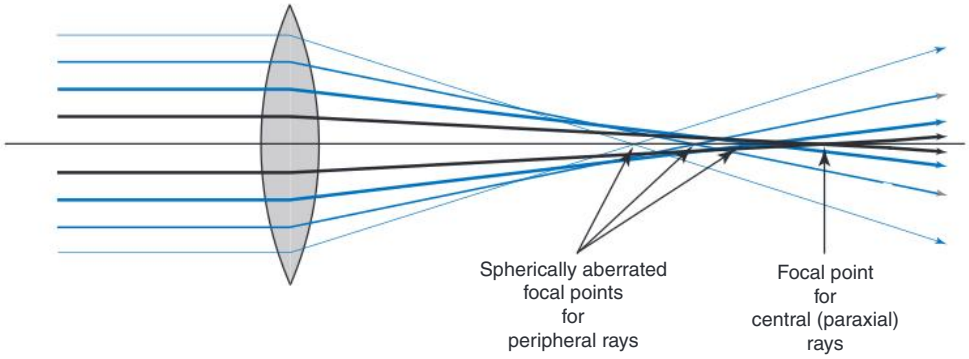


Figure 18.5 This exaggerated depiction shows that when spherical aberration is present, the closer to the edge of the lens the rays are and the shorter their focal length will be. The peripheral rays have an increasingly shorter focal length than the central (paraxial) rays. (This particular form of spherical aberration is positive spherical aberration. There is a form of spherical aberration called *negative spherical aberration* in which the peripheral rays have a longer focal length than the central rays.)

through different zones of the lens. (Zones could be considered as imaginary doughnut-shaped rings on the lens, each having a longer radius.) The focal areas of the peripheral "zones" lie in a different location than those of the more central rays. Instead of forming a single point image off the optic axis, the image appears comet or ice cream cone shaped. The point of the cone points toward the optic axis. This aberration is known as *coma* (Figure 18.6).

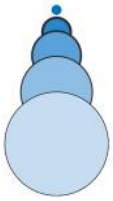


Figure 18.6 Coma is an aberration that causes light from peripheral areas of the lens to be focused farther from the true image point than it should be. Because light farther in the periphery is displaced increasingly farther from the point focus, the image is distorted in cometlike fashion as shown. The drawing is simplified to show the way the image is created. In actuality, there are unlimited "circles" of blur that blend together in a flared appearance like the tail of a comet.

Oblique Astigmatism

Oblique astigmatism is a third Seidel aberration that occurs when rays from an off-axis point pass through the spectacle lens. When a small bundle of light strikes the spherical surface of a lens from an angle, oblique astigmatism causes the light to focus as two line images known as the tangential and sagittal images instead of a single point (Figure 18.7). It is as if the light were passing through an astigmatic lens rather than a spherical lens.

The distance between the two line foci that occurs in oblique astigmatism is called the *astigmatic difference*. When expressed in diopters, this difference is called the *oblique astigmatic error*. Oblique astigmatic error is a measure of oblique astigmatism.

Oblique astigmatism is troublesome for the spectacle lens wearer and must be taken into consideration when designing spectacle lenses. Oblique astigmatism may be reduced by finding the optimum base curve for a given lens power. There is a graph that shows the best lens form(s) for eliminating oblique astigmatism at a particular off-axis viewing angle. This graph is in the shape of an ellipse and is called *Tscherning's ellipse* (Figure 18.8). The size of the ellipse may vary, depending on the viewing distance and angle the lens designer uses when trying to reduce oblique astigmatism.

There are two synonyms for oblique astigmatism. These are *radial astigmatism* and *marginal astigmatism*.

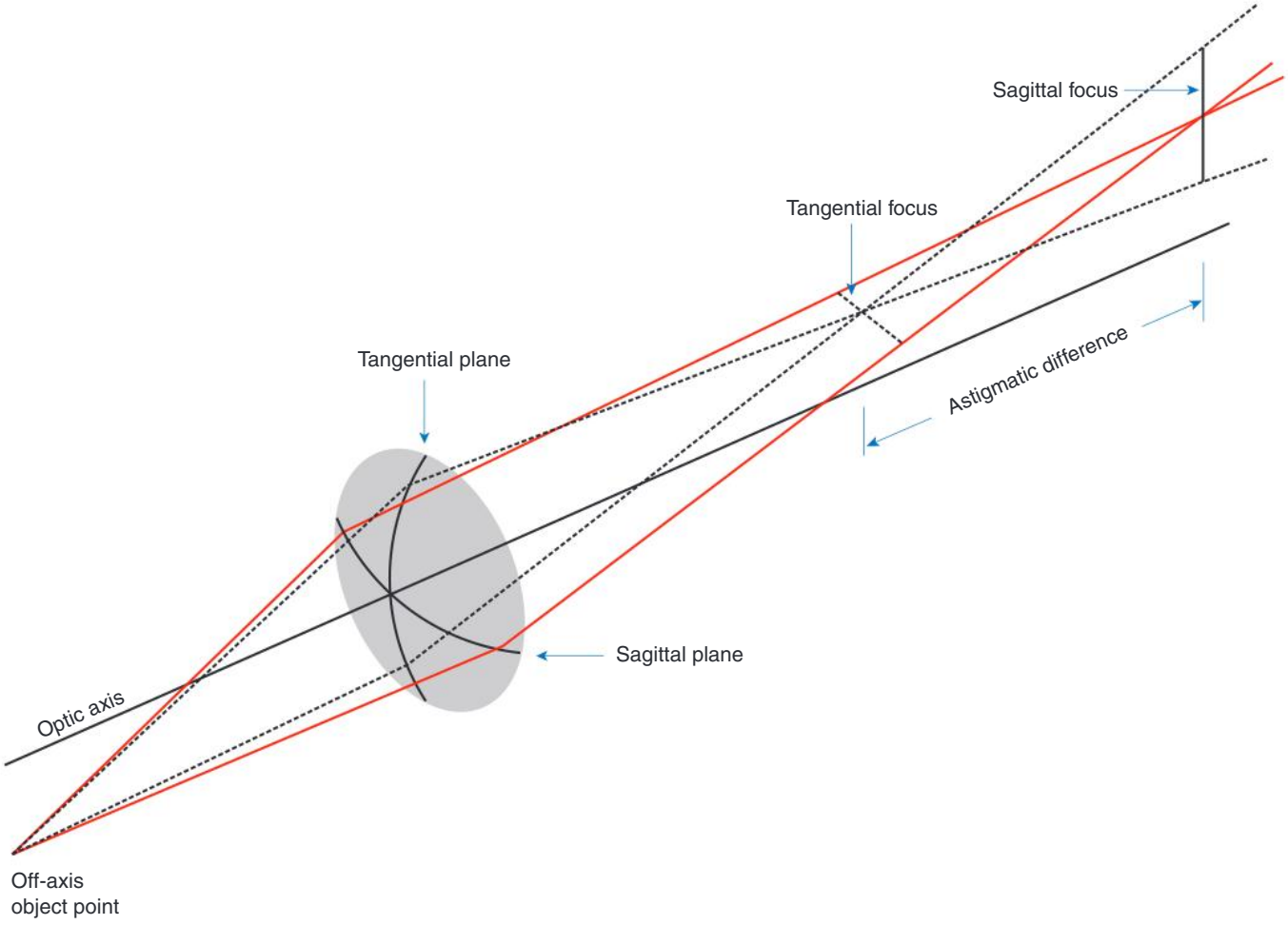


Figure 18.7 Oblique astigmatism is caused because light striking the lens in the tangential plane focuses at one line focus, whereas light striking the lens in the sagittal plane focuses at another line focus. (The tangential plane of the lens is the plane that intersects the optic axis and the off-axis object point. The sagittal plane is 90 degrees away from the tangential plane.)

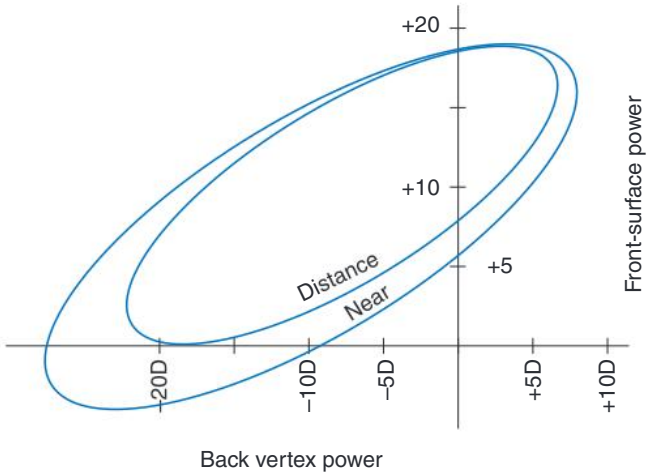


Figure 18.8 A Tscherning's ellipse graphically shows the base curves needed to correct for oblique astigmatism. There is a different ellipse for each viewing distance. Although there is normally only one ellipse shown on a graph at a time, there are two Tscherning's ellipses shown here—one for distance and the other for near. By showing these two at the same time, it is easier to see how the choice of the best base curve for a lens will depend upon its intended use. (From Keating MP: Geometric, physical and visual optics. ed 2. Boston, 1988, Butterworth-Heinemann.)

The Effects of Tilting Lenses

Oblique astigmatism is also manifested when lenses are tilted in front of the eye. This happens because the optic axis of the lens tilts with the lens. The object of regard, which was on the optic axis of the lens, now becomes an off-axis object or point. Because the lens is angled in reference to the object of regard, oblique astigmatism will affect the image of that point. Before the tilt, the object, located on the optic axis, formed a single-point image based on the actual spherical power of the lens. With tilt, the image is now formed as if it were refracted through a new sphere and cylinder.

The new sphere and cylinder powers manifested through the "old" tilted lens can be determined by first finding the effective powers in the sagittal and tangential meridians of the lens.[5] It turns out that the sagittal meridian coincides with the axis of lens tilt. For a pantoscopic tilt, the axis of tilt is along the horizontal or 180-degree meridian, and so the horizontal meridian is the sagittal meridian. For a face-form tilt, the axis of tilt is along the vertical or 90-degree meridian, and so the vertical meridian is the sagittal meridian. (The tangential meridian is perpendicular to the sagittal meridian as shown in Figure 18.7.)

The effective power in the sagittal meridian is

$$F_s = F\left(1 + \sin^2\frac{\theta}{2n}\right)$$

where

F_s = the power in the sagittal meridian,
F = the power of the lens being tilted (i.e., the "old" lens),
θ = the angle of tilt, and
n = the refractive index of the lens.

The power in the tangential meridian is

$$F_t = F\left(\frac{2n + \sin^2\theta}{2n\cos^2\theta}\right)$$

The difference between sagittal and tangential powers is the amount of astigmatism induced. In other words, the cylinder power induced is

$$\text{induced cylinder} = F_T - F_S$$

For a spherical lens, the equation for tangential power is sometimes skipped, and the induced cylinder is directly approximated by

$$\text{Induced cylinder} \approx F \tan^2\theta$$

where

F = the power of the lens being tilted (i.e., the "old" lens) and
θ = the angle of tilt.

The sign (+ or −) of the induced cylinder is the same as the sign of the tilted lens. When tilting a sphere, the axis of the induced cylinder is the same as the axis of tilt. Finding the induced cylinder with this equation is not as accurate as finding the difference between tangential and sagittal powers.

Important Bottom Line Results to Remember

Here are some important things to remember about what happens to the induced power of the lens when lenses are tilted.

1. The new sphere power will be greater than the old sphere power of the lens. Higher plus for plus lenses; higher minus for minus lenses.
2. The new, induced cylinder will have the same sign as the sign of the lens being tilted. If the tilted lens is plus in power, the new induced cylinder will be a plus cylinder. If the tilted lens is minus in power, the new induced cylinder will be a minus cylinder.
3. The axis of the new, induced cylinder will be in the meridian of tilt. If the tilt is pantoscopic, the axis of the induced cylinder will be axis 180 degrees. If the tilt is face-form or wrap-around, the axis will be 090 degrees.

Wrap-Around Prescription Lenses

Wrap-around prescription eyewear presents unique optical problems that can require compensating power changes in lens powers to keep the optical effect of the prescription as intended. Here is an example that demonstrates the effects of lens tilt and shows what can happen optically to a prescription placed in a wrap-around frame if no compensation is made.

Example 18.4

Suppose a −5.75 D lens is made from polycarbonate material of index 1.586. To keep from complicating the problem, we will say that there is no lens decentration required since the wearer's interpupillary distance equals the frame A size added to the frame's distance between lenses measurement (A + DBL). This means that there would be no face form required to allow for lens decentration. However, this lens is placed in a "wrap" frame having a lens tilt of 25 degrees around the 90-degree axis. (Some wrap frames can approach 30 degrees in their tilt.[5]) What power will this tilted lens deliver when placed in this frame?

Solution

First, we find the sagittal power of the new induced lens power. This will become the new sphere power.

$$F_S = -5.75\left(1 + \frac{\sin^2 25}{2(1.586)}\right)$$
$$= -5.75\left(1 + \frac{0.1786}{3.172}\right)$$
$$= -5.75(1.0563)$$
$$= -6.07\,\text{D}$$

Next, we will find the tangential power in the other meridian.

$$F_T = F\left(\frac{2n + \sin^2\theta}{2n\cos^2\theta}\right)$$
$$= -5.75\left(\frac{2(1.586) + \sin^2 25}{2(1.586)\cos^2 25}\right)$$
$$= -5.75\left(\frac{3.172 + 0.179}{(3.172)(0.821)}\right)$$
$$= -5.75\left(\frac{3.351}{2.605}\right)$$
$$= -7.40\,\text{D}$$

Taking the difference between sagittal and tangential meridians, we find the induced cylinder power to be

$$\text{Induced cylinder} = F_t - F_s$$
$$= -7.40 - (-6.07)$$
$$= -1.33\,\text{D}$$

The power the lens delivers to the eye is

$$-6.07\ -1.33 \times 090.$$

It is evident that the effect of tilting the lens can become large and will be problematic unless the effect of tilt is considered and the power of the lens changed to compensate for the induced change in sphere and cylinder. Prescriptions of even modest power may be significantly affected by lens tilt when placed in a frame with a large amount of wrap-around.

To overcome this problem, a compensating power must be calculated ahead of time.

Example 18.5

What powered lens of 1.586 index of refraction would be needed to produce a −5.75 D sphere after the frame has been given a face-form wrap-around that tilts the lens 25 degrees?

Solution

This problem is essentially asking how we must compensate a −5.75 D sphere prescription so that it comes out right in a frame with a 25-degree tilt for each lens. To figure this out, we need to work backward. In other words, using the formula

$$F_s = F\left(1 + \sin^2\frac{\theta}{2n}\right)$$

We need to end up with F_s equal to −5.75 D. We need to find the value of F for the meridian of tilt. In this case, the meridian of tilt is the 90-degree meridian.

$$F_s = F\left(1 + \sin^2\frac{\theta}{2n}\right)$$
$$-5.75 = F\left(1 + \frac{\sin^2 25}{2(1.586)}\right)$$
$$-5.75 = F\left(1 + \frac{0.179}{3.172}\right)$$
$$-5.75 = F(1.056)$$
$$F = \frac{-5.75}{1.056}$$
$$F = -5.45\,\text{D}$$

So, the needed power in the 90-degree meridian is −5.45 D.

Since the lens is a sphere, we also need to end up with a power of −5.75 D in the tangential (180-degree) meridian. Here, we also work backward using the formula

$$F_T = F\left(\frac{2n + \sin^2\theta}{2n\cos^2\theta}\right)$$

We want a power of −5.75 for F_T when we are finished. Therefore,

$$F_T = F\left(\frac{2n + \sin^2\theta}{2n\cos^2\theta}\right)$$
$$-5.75 = F\left(\frac{2(1.586) + \sin^2 25}{2(1.586)\cos^2 25}\right)$$
$$-5.75 = F\left(\frac{3.172 + 0.179}{(3.172)(0.821)}\right)$$
$$-5.75 = F\left(\frac{3.351}{2.605}\right)$$
$$-5.75 = F(1.286)$$
$$F = \frac{-5.75}{1.286}$$
$$F = -4.47\,\text{D in the } 180-\text{degree meridian}$$

If we have −5.45 D in the 90-degree meridian and −4.47 D in the 180-degree meridian, the theoretical lens needed is −4.47 −0.98 × 180. When using free-form (digital) surfacing, these powers would not be rounded but used as listed. If they were to be rounded to the nearest quarter diopter, the lens used would be −4.50 −1.00 × 180. This is what the lenses will read with the lensmeter. However, when being worn, this lens will behave as if it had a power of −5.75 D sphere—the same power as the original prescription.

Tilting of spherocylinders. When tilted, a spherocylindrical lens also has induced power changes. For either pantoscopic or face-form tilt of a spherocylinder lens with axis 90 or 180, the tilted spherocylindrical lens acts like a spherocylinder with a new sphere power and a new cylinder power. The principal meridians of the "old" (or untilted) lens are horizontal and vertical. The lens power chosen to calculate the effective sagittal power (F_S) is the power of the spherocylinder in the sagittal meridian. The lens power chosen to calculate the effective tangential power (F_T) is the power of the spherocylinder in the tangential meridian.

After calculating the new powers, one can then put them on a horizontal and vertical power cross and, from it, determine the new spherocylindrical parameters (sphere, cylinder, *and* axis) in the usual manner.

For pantoscopic or face-form tilt of a spherocylindrical lens with an oblique axis, there is an effective change in cylinder axis and an effective change in the sphere and cylinder powers. Here, the computations are more complicated and require resultant calculations combining obliquely crossed cylinders. It is also feasible to work backward as we did previously to find what prescription must be placed in a wrap-around frame to prevent unwanted power changes. For an explanation of how this may be done, see Keating MP: Geometric, Physical, and Visual Optics.[5]

Induced prism with wrap-around eyewear. There are also induced prismatic effects associated with tilting lenses. To see how this works, take a lens prescription and center the optics in a lensmeter with the

prescription correctly neutralized. Then, tilt the prescription to simulate a wrap-around effect. The prism that appears is a result of that lens tilt.

This prismatic effect depends on the angle of tilt, the steepness of the base curve, the index of the material, and the thickness of the lens. It is predictable using the equation[6]

$$\Delta = 100 \tan\theta \frac{t}{n} F_1$$

where

Δ = the prism induced.
θ = the angle of tilt.
t = the thickness of the lens at the reference point in meters.
n = lens refractive index.
F_1 = the front curve of the lens.

Notice that, contrary to what might be expected, the refractive power of the lens is not a part of this equation for prismatic effect—but front curve lens power, or base curve, is an important part.

The base direction of the prism induced is determined by the angle at which the light enters the lens. If the light enters the lens from above the optic axis, the orientation of the prism will be base down. If the light enters the lens from the left of the lens, then the base of the induced prism is to the right.

For lenses with pantoscopic tilt, the bottom of the lens is tilted in toward the face. Light coming from straight ahead strikes the lens as if it were entering from above. Therefore, the prism induced is base down. Since the induced prism is base down for both right and left lenses, there is a net prismatic effect of zero. Both lenses cause the image to move up by basically the same amount, so no compensation would be required.

For wrap-around lenses, the right lens is tilted such that light coming into the lens from in front of the wearer is striking the lens as if it were coming from the left (Figure 18.9). Therefore, the prism base direction is base right. For the right eye, base right is the same as base out. For the left eye, the base direction will be base left, which is also base out. With both eyes having base out prism, the eyes must turn slightly inward to retain a single image of the object viewed. To compensate for induced base-out prism, base-in prism would need to be used. This is true even for wrap-around lenses that have zero refractive power. As long as the frame has wrap-around and the front of the lens is curved, a prismatic effect is induced. However, if the front of the lens were flat, then the induced prismatic effect would drop to zero.

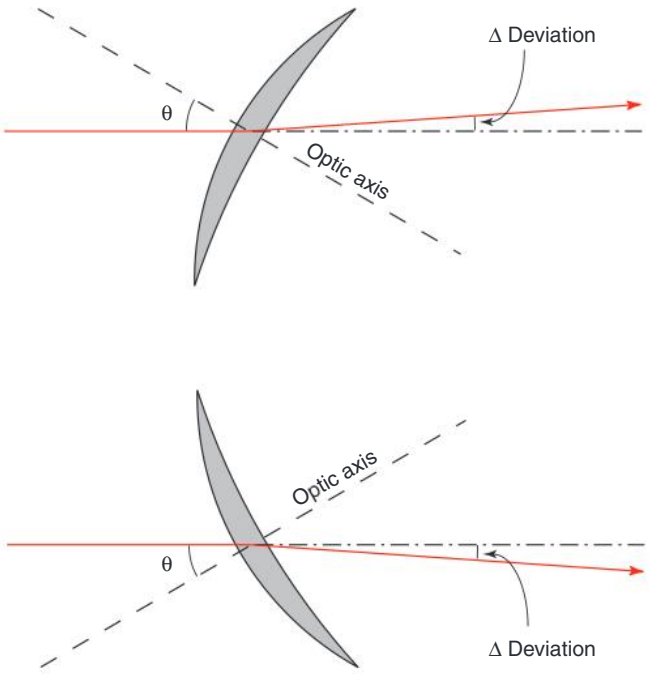


Figure 18.9 Lens tilt will cause a slight amount of prismatic effect. The amount of prism deviation is equal to

$$\Delta = 100 \tan\theta \frac{t}{n} F_1.$$

In this figure, θ is the angle between the optic axis and the incoming central ray.

Example 18.6

A prescription is to be placed into a pair of wrap-around frames. Each lens has a wrap angle of 25 degrees. It is ground with a +8.00 D front-surface refractive power. The lens is polycarbonate and has a 2.0-mm center thickness. What amount and direction of prism is induced? If compensatory prism is placed in the glasses to counteract the induced prism, what base direction would be used?

Solution

Using the formula for prism induced by tilt, the prism amount is

$$\Delta = 100 \tan\theta \frac{t}{n} F_1$$
$$\Delta = 100 \tan 25 \left(\frac{0.002}{1.586}\right) 8$$
$$= 0.47\Delta$$

The amount of prism is 0.47Δ. Since the light enters the lens at an angle on the nasal side, the prism base direction is on the other side, which is base out. The induced prism is 0.47Δ base out per eye. The prism needed to compensate for 0.47Δ induced base-out prism is 0.47Δ base in per eye.

For orders with significant wrap-around, use a laboratory that is experienced with making any necessary compensatory changes in refractive power and prism caused by lens tilt.

Intentionally Tilting a Lens to Prevent Problems

Earlier lens tilt examples present situations in which the wearer's interpupillary distance (PD) and the frame A size added to the frame's distance between lenses (A + DBL) dimensions are the same. In other words, there is no necessity for decentration. Yet most prescriptions do require at least a small amount of decentration inward since the wearer's PD is generally smaller than the frame's A + DBL measurements.

If a prescription *does* require some decentration inward, then the frame front *should* have a certain amount of face form. A lens with decentration inward and no face form will end up having tilt at the OC. This is explained in more detail in Chapter 5. (Note especially Figures 5.1, 5.2, and 5.3.) Decentration that is compensated for with a certain amount of face form will actually *prevent* the decentered lens from being tilted at the OC. However, adding more face form than the needed amount will end up causing those unintended sphere and cylinder power errors that have just been described. The same principle applies to pantoscopic tilt as may be seen in Figures 5.4 through 5.7.

Curvature of Field (Power Error)

The fourth Seidel aberration is called curvature of field or power error. If a designer makes a lens that is completely free of oblique astigmatism,

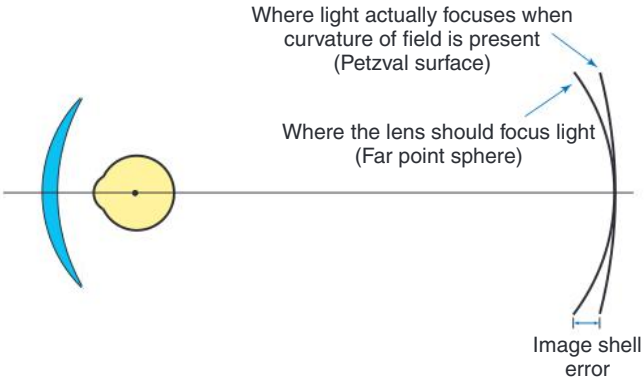


Figure 18.10 The aberration, curvature of field, occurs when light entering the peripheral areas of the lens does not focus where it should—namely, on the far point sphere. (The far point sphere is curved because the eye turns to see objects toward the periphery of the lens.) Instead, light focuses on what is called the *Petzval surface*. The Petzval surface is formed when oblique astigmatism is corrected. Another name for the Petzval surface is the *image sphere*.

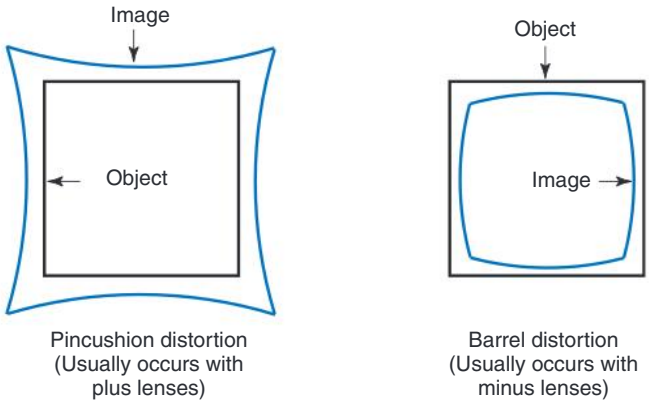


Figure 18.11 Magnification occurs with plus lenses, and minification occurs with minus lenses. However, the magnification is not even across the lens. This results in the types of distortion of the magnified or minified images shown here.

there will still be another aberration the wearer encounters when looking through the periphery of the lens. This fourth of Seidel's five aberrations is called *curvature of field*, or *power error*. Power error is the more descriptive term because this aberration causes the spherical component of the lens to have the effect of being off-power in the periphery when worn (Figure 18.10). (The dioptric difference between the place where an image formed in the periphery actually focuses and where it should focus is called the *image shell error*.)

It is important to use the manufacturer's recommended base curve for each given lens power. The optimum base curve will ensure that oblique astigmatism and power error are held to a minimum. When using the wrong base curve, the wearer will not be able to see as well through the periphery of the lens.

Distortion

The fifth and last of the five Seidel aberrations is distortion. *Distortion* occurs because there is a different magnification in different peripheral areas of the lens. This varying magnification occurs in proportion to the distance of those areas from the OC of the lens. For plus lenses, *magnification* increases toward the periphery; in minus lenses, *minification* increases toward the periphery.

When looking at the center of a square window through a high plus lens, the corners of the window are farther away from the center of the lens than the middle of the sides or middle of the top and bottom of the window. This means the corners will be magnified more. This makes the window look like a pincushion (Figure 18.11). This type of distortion is known as *pincushion distortion*.

For minus lenses, the corners would receive less magnification than the middle of the sides, tops, or bottoms of the window, causing the window to have a barrel-like appearance. Hence, the name *barrel distortion*.

Spectacle Lens Design

As noted previously, some aberrations are more important than others when designing spectacle lenses. To summarize:

- Chromatic aberration is important when considering possible high-index materials to use for spectacle lenses.
- Because of pupil size, the Seidel aberrations of spherical aberration and coma are less problematic.
- The three Seidel aberrations proving to be most troublesome in ophthalmic lenses are oblique astigmatism, power error, and distortion.

Looking at design possibilities simplistically, there are three possibilities:

1. A lens designer can correct the oblique astigmatism completely, leaving the power error uncorrected. A lens designed in this fashion is referred to as a *point focal lens*.
2. A designer can concentrate on eliminating power error but choose to leave residual astigmatism uncorrected. This type of lens is referred to as a *Percival form lens*.
3. A designer can design a lens referred to as a *minimum tangential error form* that is a compromise between the first two choices. At this point in time, designing a lens that is strictly a "point focal" or a "Percival" form lens is not likely. A lens that compromises between the two forms is common practice.

It should be noted that all three of the previous choices are referred to as either *corrected curve* or *best form* lenses.

Four Variables of Lens Design

There are four variables the designer can use to arrive at the best form for an individual lens of a specific power. These four are:

1. Vertex distance
2. Lens thickness
3. Refractive index
4. Front and back lens surface powers

For a single-vision series of lenses, the first three variables must be decided for the whole series. Therefore, the only practical variables left to work with are front- and back-surface powers.

The Importance of Using the Correct Base Curve for Surfaced Lenses

When a laboratory receives a single-vision series of finished lenses, the base curve of the lens is set. When the lens is removed from the package, the only choices left are related to lens edging. When a lens must be surfaced, however, the laboratory looks at the desired lens power and chooses a lens blank with a front (base) curve appropriate for that particular power. Lens designers have already recommended certain base curves for specific lens powers, so the laboratory usually tries to remain within those guidelines.

Failure to select the correct base curve for a given lens power will not affect the quality of vision a person has through the center of the lens. However, it will reduce the quality of vision through the periphery of the lens.

By using the correct base curve, the most troublesome monochromatic aberrations can be reduced. By looking at Tscherning's ellipse

(see Figure 18.8), we see that it is possible to correct for oblique astigmatism for sphere powers ranging from approximately +7.00 D to −23.00 D. (It should be noted that the phrase "correct for oblique astigmatism" means that oblique astigmatism can be eliminated for one specific viewing distance and one oblique viewing angle. At other distances and viewing angles, oblique astigmatism will be considerably reduced but not eliminated.) For powers outside of the +7.00 D to −23.00 D range, there is no spherical base curve that will eliminate oblique astigmatism. Fortunately, there is another option. That option is to use an aspheric lens.

It should be noted that the Tscherning's ellipse also shows that there are really two possible base curves that can correct for oblique astigmatism. The lower half of the ellipse corresponds to the lens form that is close to those customarily used today.

APPROPRIATE BASE CURVES

It is possible to create the same power using an almost infinite variety of lens forms. A lens with a front curve of +2.00 D and a back curve of −6.00 D will produce the same power that a lens with a +3.00 D front curve and a −7.00 D back curve will produce. If many lens forms produce the same power, is there a specific front curve that should be chosen for a given lens power?

Although there is a range of possible lens forms that will prove acceptable, there are limits beyond which the overall results will be poor. If an incorrect base curve is selected, the quality of vision is acceptable while looking straight ahead, but vision will be degraded when turning the eyes to view an object off to the side. This effect is due to lens aberrations brought about by an incorrect lens form.

Manufacturers' Recommendations

Lens manufacturers recommend specific base curves for each lens power. These recommendations list the range of powers and tell which base should be used for those powers.

A General Guideline

The power of a lens determines its shape.

- Plano lens powers usually have back-surface curves close to −6.00 D.
- As lens power becomes more minus, the back surface steepens and the front surface flattens.
- As plus lens power increases, the back surface becomes progressively flatter, whereas the front curve becomes steeper.
- From the front, minus lenses look flatter and plus lenses look steeper.

Base Curve Formulas

One method for estimating the range in which an appropriate base curve might be found is to use a simplified formula derived from precalculated base curves. Such a formula is not a replacement for manufacturers' recommendations. One such formula is *Vogel's formula,*[7] which states that, for plus lenses, the base curve of the lens equals the spherical equivalent of the lens power plus 6 D. Written as a formula this is

$$\text{Base curve}_{(plus\ lenses)} = \text{Spherical equivalent} + 6.00\ \text{D}$$

(The *spherical equivalent* of a lens is the sphere power plus half of the cylinder power.) For minus lenses, Vogel's formula for base curve begins with the spherical equivalent of the lens, divides the spherical equivalent by 2, then adds 6 D. Written as a formula this is

$$\text{Base curve}_{(minus\ lenses)} = \frac{\text{Spherical equivalent}}{2} + 6.00\ \text{D}$$

These formulas are summarized in Box 18.2.

BOX 18.2 Vogel's Formula for Base Curves*

Plus Lenses

$$\text{Base curve}_{(plus\ lenses)} = \text{Spherical equivalent} + 6.00\ \text{D}$$

Minus Lenses

$$\text{Base curve}_{(minus\ lenses)} = \frac{\text{Spherical equivalent}}{2} + 6.00\ \text{D}$$

Spherical Equivalent

$$\text{Spherical equivalent} = \text{Sphere power} + \frac{\text{Cylinder power}}{2}$$

*Note: These base curves are estimates for glass and low-index plastic lenses and will estimate a somewhat higher base curve for plus lenses than would be used. These formulas are for general reference purposes. They should not be used for actual lens production.

Remember that this formula is to help in determining approximately what base curve might be expected for a given lens power. Actual base curves for lenses will vary. Plus lenses will be somewhat flatter than calculated, and plus lenses of higher index of refraction may be considerably flatter.

Example 18.7

Using Vogel's formula, find an approximate base curve for a lens having a power of +2.00 D sphere.

Solution

For spheres, there is no need to calculate a spherical equivalent. So for this lens, the base curve is

$$\begin{aligned}\text{Base curve}_{(plus\ lenses)} &= +2.00\ \text{D} + 6.00\ \text{D}\\ &= +8.00\ \text{D}\end{aligned}$$

Example 18.8

Suppose a lens has a prescription of +5.50 − 1.00 × 070. Using Vogel's formula, what is the base curve?

Solution

Since this lens has cylinder, we begin by finding the spherical equivalent of the lens.

$$\begin{aligned}\text{Spherical equivalent} &= +5.50 + \frac{-1.00}{2}\\ &= +5.00\ \text{D}\end{aligned}$$

The approximate base curve is

$$\begin{aligned}\text{Base curve}_{(plus\ lenses)} &= +5.00\ \text{D} + 6.00\ \text{D}\\ &= +11.00\ \text{D}\end{aligned}$$

Example 18.9

A minus lens has a power of −6.50 −1.50 × 170. Using Vogel's formula, what is the approximate base curve?

Solution

The spherical equivalent of −6.50 −1.50 × 170 is

$$\begin{aligned}\text{Spherical equivalent} &= -6.50 + \frac{-1.50}{2}\\ &= -7.25\ \text{D}\end{aligned}$$

The base curve formula for minus lenses is different than that for plus lenses; therefore, the approximate base curve is

$$\text{Base curve}_{(\textit{minus lenses})} = \frac{-7.25}{2} + 6.00\,\text{D}$$
$$= -3.62\,\text{D} + 6.00\,\text{D}$$
$$= +2.38\,\text{D}$$

Rounded to the nearest half diopter, this is +2.50 D. (In practice, base curve rounding would be to the nearest base curve in the series stocked by the laboratory.)

Considering Right and Left Lenses as a Pair

Up to this point, we have only been choosing the base curve based on the power of one individual lens. This works fine if both left and right lenses have the same power. But if the powers are different in the left and right eyes, one lens might call for one base curve, whereas the other lens requires a different curve. This could be problematic in certain instances.

Consider the situation in which one lens in a pair has a power that is only 0.50 D stronger than that of the other. Yet, when looking at manufacturer's recommendations for each lens, the right and left base curve powers straddle two available base curves. (Lens blanks come in power jumps, such as 2, 4, 6, etc.) Suppose that one lens calls for a + 6.00 base, whereas the other calls for a + 8.00 base. If the lenses were chosen with two different base curves, there would be both a visible difference in the appearance of the two lenses and a difference in magnification created between the images seen by the right and left eyes. Therefore, a decision needs to be made to modify the base curve(s).

Because an error in base curve selection is worse for high-powered lenses than for lenses closer to zero power, from an *optical* standpoint, the higher-powered lens would drive the choice.

This means that the best choice optically will be the base curve corresponding to the lens with the higher magnitude of dioptric power. Here are some examples:

- Where both lenses are plus, the steeper base curve (higher numerical base curve) of the two will be on the higher plus lens. So the steeper base curve would be the correct optical choice for both eyes. However, from a cosmetic standpoint, this choice may not always be followed.
- For minus lenses, the higher minus lens drives the base curve choice. The higher the minus power, the flatter the base curve will be. So, if both lenses are minus, the flatter base curve of the two should be chosen for both eyes.
- If one lens is plus and one lens is minus, optically the base curve for the lens with the highest numerical value would be chosen for both eyes.

It is usually advisable to maintain individual lens base curve choices when the difference between the right and left base curves is greater than 2 D. This is because a correctly chosen base curve will produce clear vision, regardless of whether the wearer is looking through the center or off toward the edges. If the recommended base curve is changed too much, vision in the periphery of the lens will be poor. (Aniseikonia considerations may also influence base curve choice. For more on aniseikonia and base curve, see Chapter 21.)

Other Factors That Modify Base Curve Choice

Metal frame eyewires have been curved to best accept a lens with a six-base curve since, historically, this has been the most common base curve. However, some frames may be designed with even a lower plus four base curve in mind. Lower base lenses may stay in the frame more easily. Also, aspheric plus lenses come with flatter base curves. Because of frame design, prescriptions that would normally have steeper base curves may have those curves flattened somewhat so that the lenses will stay in the frame better. (Instead of just flattening the lens, a better choice may be to use an aspheric lens. Aspheric plus lenses can be made on flatter base curves without degrading optical quality.)

Plastic frame styles that have a poor lens retention record may retain their lenses better if the lenses have flatter base curves.

Prescriptions with *large amounts of prism* end up being thicker. Lens thickness increases lens magnification and makes the eye look larger. This is especially true for plus lenses. Much of this magnification comes from a steep front curve. This means that magnification may be reduced by using a flatter base curve. As an added benefit, large prisms are easier to work with when produced on a somewhat lower base curve.

ASPHERIC LENSES

What Is an Aspheric Lens?

The term *aspheric* means "not spherical." The curvature of a spheric lens is continuously uniform with a consistent radius of curvature throughout its entire surface like that of a ball or sphere. An aspheric lens surface changes shape. It does not have the same radius of curvature over the entire surface. Aspheric lenses are, generally speaking, based on a surface curvature that comes from a conic section. A conic section is a slice through a cone. There are four basic types of conic sections (Figure 18.12). These are:

1. *A circle:* A circle is the shape formed by a horizontal plane or a slice through an upright cone.

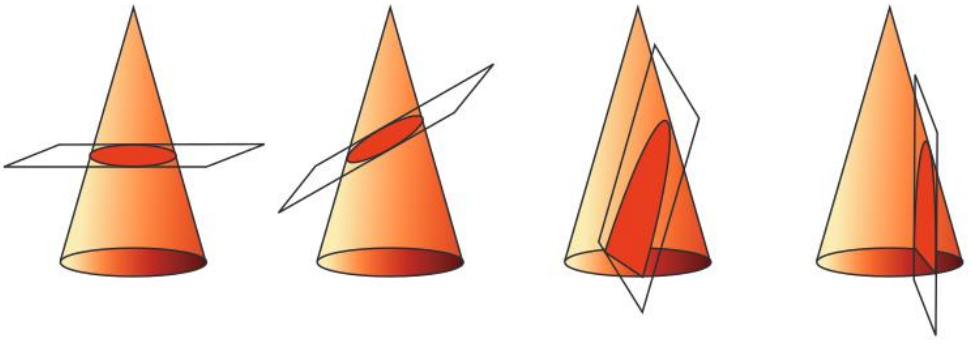


Figure 18.12 Conic sections create the curves that are often used for lens surfaces. The circle is used for spherically based lenses. The ellipse, parabola, and hyperbola are used for aspheric surfaces.

2. *An ellipse:* An ellipse is a shape formed by an angled plane through a cone that does not intersect the base of the cone.
3. *A parabola:* A parabola is a curve that is formed by the intersection of a cone with a plane having one side parallel to the side of the cone.
4. *A hyperbola:* A hyperbola is a shape formed when a cone is intersected by a plane that makes a greater angle with the base of the cone than the side of the cone makes with its base.

When these shapes are used as the shape for the front of a lens, they compare as shown in Figure 18.13.

Aspheric surfaces have a changing radius of curvature and thus a varying amount of surface astigmatism everywhere except at the center of the lens surface. This means that it is possible to select a specific type of aspheric surface that will neutralize unwanted oblique astigmatism. For example, suppose we want to use a lens that has a considerably flatter base curve than normal. Just flattening the base curve on a spherically based lens will mean increased oblique astigmatism resulting in poor peripheral optics. Yet this flatter base can be used successfully if a type of aspheric surface is chosen that has a matching but counterbalancing amount of surface astigmatism compared with that of the oblique astigmatism induced by the flatter base curve.

Purposes for Using an Aspheric Design

There are at least five good reasons for producing a lens that has an aspheric surface.

1. The first reason is to be able to optically correct lens aberrations.
2. The second reason is to allow the lens to be made flatter, thereby reducing magnification and making it more attractive.
3. The third reason is to produce a thinner, lighter-weight lens.
4. A fourth reason may be to ensure a good, tight fit in the frame.
5. The fifth reason is to make a lens with progressive optics.

Asphericity for Optical Purposes

As stated earlier, for most powers, it is possible to produce a lens that is optically sound using regular, spherical surfaces. Once lens powers go beyond the +7.00 D to −23.00 D range, however, it is necessary to use an aspheric design.

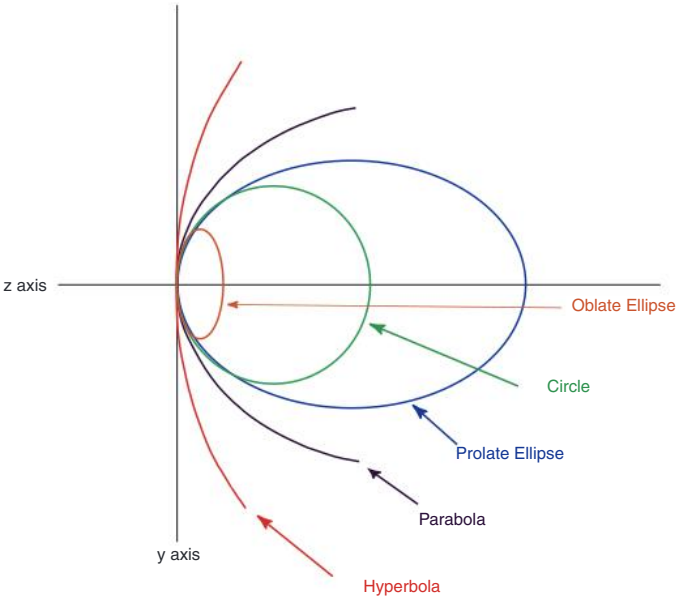


Figure 18.13 This figure shows how geometric conic sections could be used on front or back lens surfaces to produce different types of asphericity. (From Jalie M: Ophthalmic lenses & dispensing, ed. 2, Boston, 2003, Butterworth-Heinemann).

In the middle of the lens, near the OC, an aspheric lens surface starts out as any other spherical surface. Then at a certain distance from the OC, the lens surface gradually changes its curvature at a rate calculated to offset peripheral aberrations. (This concept will be discussed in greater depth in the section on high plus lenses later in the chapter.)

Asphericity for Flattening Purposes

For lenses with spherical base curves, higher plus power always results in steeper base curves (Figure 18.14). Unfortunately, for high plus lenses, from a cosmetic standpoint, the steeper the base curve is, the worse the lenses look. Choosing a flatter base curve will make the lens look better. The lenses appear less bulbous, and, because flatter base curves reduce magnification, the eyes don't look so big. In addition, the lens is also somewhat thinner. Cosmetically the lens does look better. Unfortunately, just flattening a regular plus lens results in bad optics. In the periphery, the sphere power will be off. This is because of the aberration of power error. There will be unwanted cylinder in the periphery. This is caused by the aberration of oblique astigmatism (Figure 18.15).

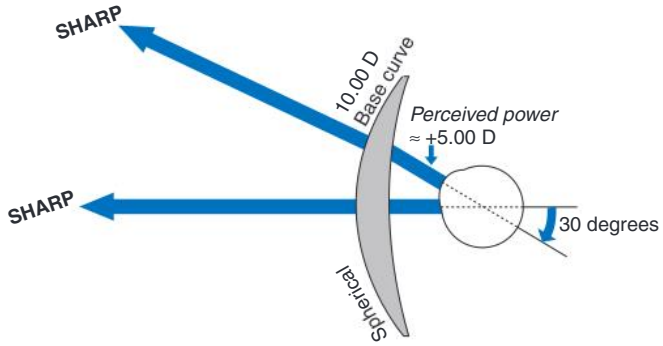


Figure 18.14 The +10.00 D front surface of this +5.00 D lens is optically appropriate. However, it makes the lens looks considerably steeper and causes magnification to increase. Even so, this spherically based corrected curve lens will give sharp vision both centrally and peripherally. (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word!, Oldsmar, Fla., November, 1993, Varilux Press. Figure 1A. Courtesy Varilux Corp.)

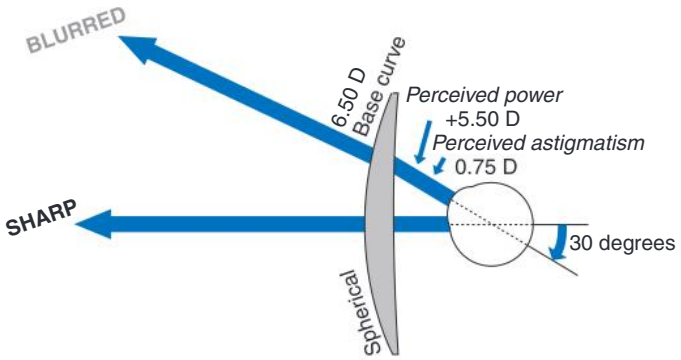


Figure 18.15 Flattening a +5.00 D lens from a +10.00 D spherical base curve lens down to a +6.50 D front curve makes it look more like a low-powered plus lens. Unfortunately, with this flat base curve, the lens is no longer optically sound. Even though the center may produce 20/20 vision, the periphery suffers from both power error and oblique astigmatism as shown in the figure. (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word!, Oldsmar, Fla., November, 1993, Varilux Press. Figure 1B. Courtesy Varilux Corp.)

Fortunately, if the front curve is flattened using an aspheric surface, it is possible to get both good cosmetics and good optics (Figure 18.16).

Another Reason for Flatter Base Curves

The steeper the base curve, the easier it is to dislodge the lens from a metal frame, so it is not unusual for a laboratory to flatten a base curve to make it fit more securely in the frame. Yet, rather than flattening a regular lens, a better option is to use a flatter, aspherically designed lens.

Asphericity for Thinning Purposes (Geometric Asphericity)

Asphericity can be specifically engineered with the express purpose of making the lens thinner. To do this for plus lenses, the lens front surface may be flattened quite a bit toward the edge. Flattening the periphery makes it possible to grind the whole lens thinner (Figure 18.17). There are several ways to thin lenses. These are often combined with one another. Figure 18.18 shows how lens thickness responds to a decrease in lens diameter, an increase in lens index, and a change to an aspheric design.

To thin minus lenses, either the peripheral portion of the lens front surface is steepened or the peripheral portion of the back surface is flattened toward the periphery, or both. This reduces edge thickness (Figure 18.19).

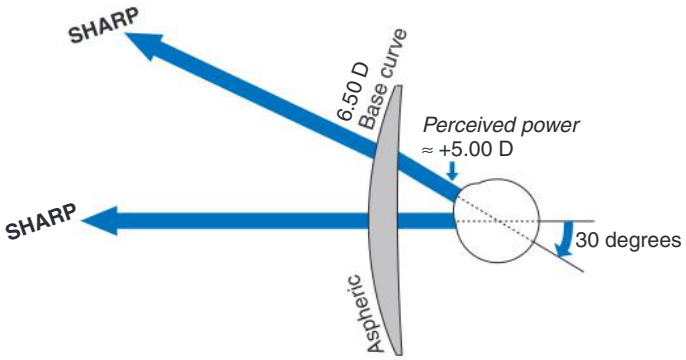


Figure 18.16 By properly using aspherics, it is possible to flatten a lens and still overcome peripheral aberrations. Here, this +5.00 D lens has been flattened to have a + 6.50 front curve, yet because the front curve is made aspheric, vision remains clear in the periphery. (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word! Oldsmar, Fla., November 1993, Varilux Press. Figure 1C. Courtesy Varilux Corp.)

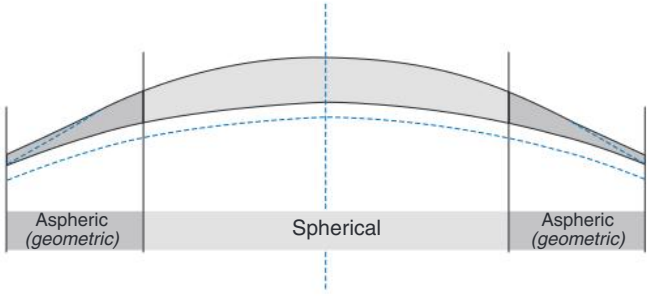


Figure 18.17 When using asphericity for the purpose of thinning a plus lens, the front surface is flattened to give the edge more thickness. For a plus lens, center thickness is limited by edge thickness. If edge thickness can be added with asphericity, then the whole lens can be thinned, and center thickness will be reduced. (Dotted lines show the shape of the unthinned, spherical lens.). (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word! Oldsmar, Fla., November 1993, Varilux Press. Figure 2A. Courtesy Varilux Corp.)

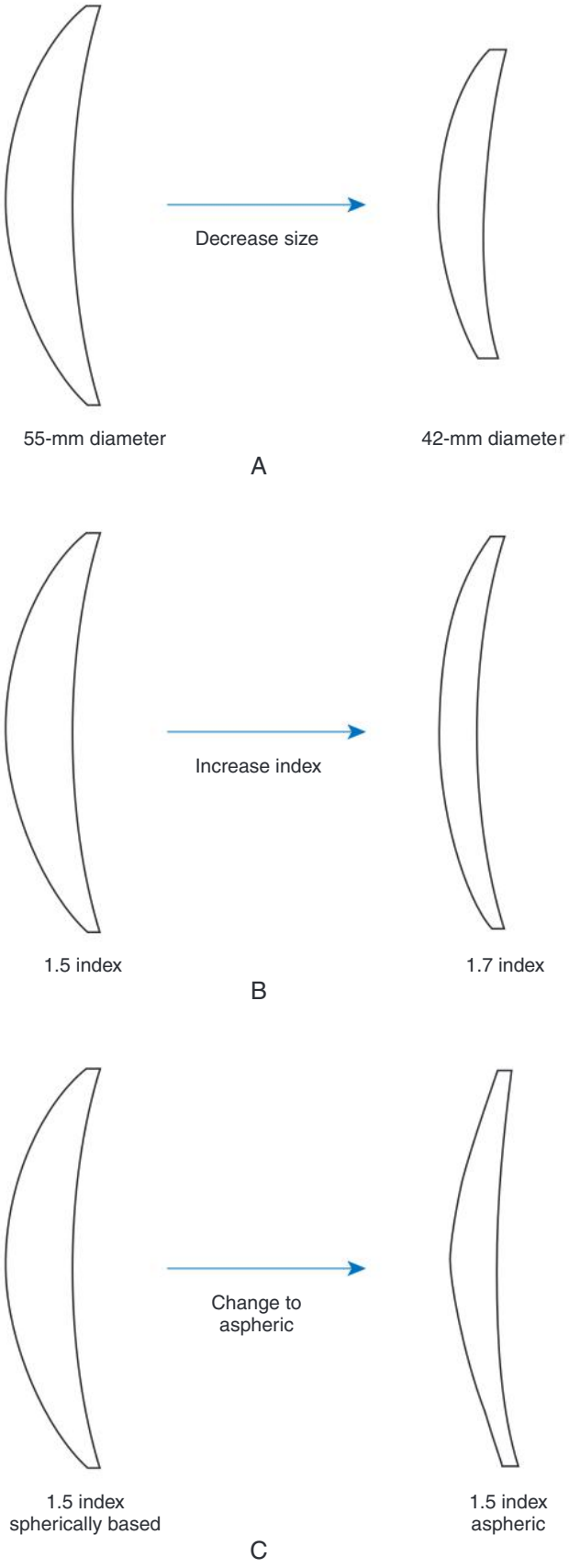


Figure 18.18 **A** shows how a plus lens may be thinned by decreasing the overall diameter of the lens. **B** shows how a lens will by thinned by increasing the refractive index. In **C,** thinning is observed when changing the front from a spherical surface to an aspheric surface.

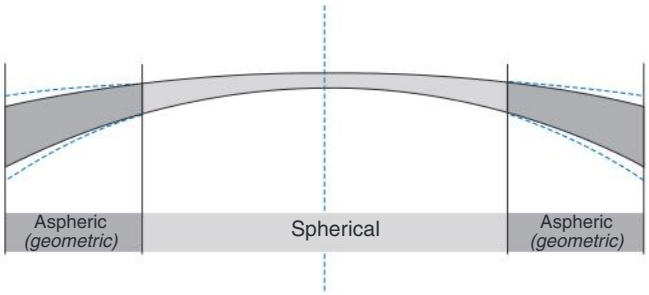


Figure 18.19 Asphericity can be used to thin the edge of a high minus lens. This is done by steepening the periphery of the front and/or flattening the periphery of the back curve. (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word! Oldsmar, Fla., November 1993, Varilux Press. Figure 2B. Courtesy Varilux Corp.)

To Ensure a Good, Tight Fit in the Frame

Traditionally, frames are made to best hold a lens that has around a +6 D base curve. Using ordinary methods for edging lenses, the steeper the base curve is, the harder it is to keep the lens tight in the frame. Since a lens can be made on a flatter base curve in an aspheric design without compromising peripheral vision, an aspheric design will help in ensuring that the lens stays in the frame.

Asphericity for Producing Progressive Power Changes

Any lens surface that is not spherical may be termed *aspheric*. Progressive addition lenses achieve their add power gain from a progressively steepening surface curvature, so progressive addition lenses are also aspheric lenses. However, there are many more factors in designing progressive lens surfaces. They should not be expected to have conventionally described aspheric surfaces.

As would be expected, the combined asphericities of the progressive addition and the gradual surface curvature changes in the upper and peripheral portions of the lens will make the surface curves considerably more complex.

ATORIC LENSES

A spherically based lens using a properly chosen base curve to create a corrected curve design can do a very good job of minimizing peripheral lens aberrations—so can an aspheric lens. In fact, an aspheric lens is able to create a lens that has a flatter base curve and is often thinner and lighter while still maintaining corrected curve quality for reduction of aberrations.

Yet, like the spherically based lens, the base curve and asphericity combination of an aspheric lens is designed for *one* specific lens power. This presents a problem for astigmatic corrections, which require *two* different powers in each principal meridian. A lens with two curves on the same surface is called a *toric* lens. Which power will be used to determine the correct amount of asphericity? Choosing to correct one power means that correction for peripheral aberrations for the other power will be less than ideal. Usually, a compromise power somewhere in between the two is chosen, with neither being optimal.

An aspheric lens gradually changes the curvature of the surface in all directions equally. With two lens powers needed in a toric lens, the rate of change in surface curvature would have to be different for each power meridian. Changing the curvature at different rates for each of the two meridians means that each rate of change can be optimized for the power in that meridian. When each meridian is optimized on a toric lens, the design is called an *atoric* lens. For a lens having cylinder power, an atoric design is able to expand the peripheral range of clearer vision beyond what is found for either a well-designed (best form) spherically based lens or an aspheric lens (Figure 18.20).

Atoric lenses should be recommended for all cylinder powers above 2.00 D, even when the spherical component of the prescription is low. They may also prove advantageous for anyone with cylinder power beyond 1.25 D. Fortunately, many of the newer high-index single-vision series of lenses being marketed are now being made as an atoric series.

Comparing the Construction of Spherically Based, Aspheric, and Atoric Lenses

Here is a quick and general comparison of the way lenses are constructed for spherically based, aspheric, and atoric lenses.

Spherically Based Lenses

- For spheres (no cylinder), the front and back surfaces are spherical.
- For spherocylinders, the front surface is spherical. The back surface carries the cylinder power and is toric.

Aspheric Lenses

- For spheres (no cylinder), the front surface is usually aspheric and the back surface is spherical. However, this may be reversed, with the front surface being spherical and the back surface being aspheric.
- For spherocylinders, the front surface is aspheric and the back surface is toric. It is not possible to correct both of the major meridians of a cylinder lens for aberrations when a lens is designed this way. Therefore, the more logical choice would be to use an atoric design instead of an aspheric one.

Atoric Lenses

- There are both spheres and spherocylinders in a given lens series that use an atoric design. This means that, in the case of spheres, the lens is really aspheric. Technically, it cannot be atoric because it has no cylinder power.
- There are several ways atoric lenses can be made. Here are the most common.
  1. A finished single-vision lens with the front surface spherical. The back surface contains the cylinder correction, and the major meridians are atoric.
  2. A semifinished single-vision lens with the front surface spherical. The back is surfaced using free-form generating. The cylinder power is on back with the major meridians being atoric. Both semifinished single-vision and multifocal lenses may be constructed this way.

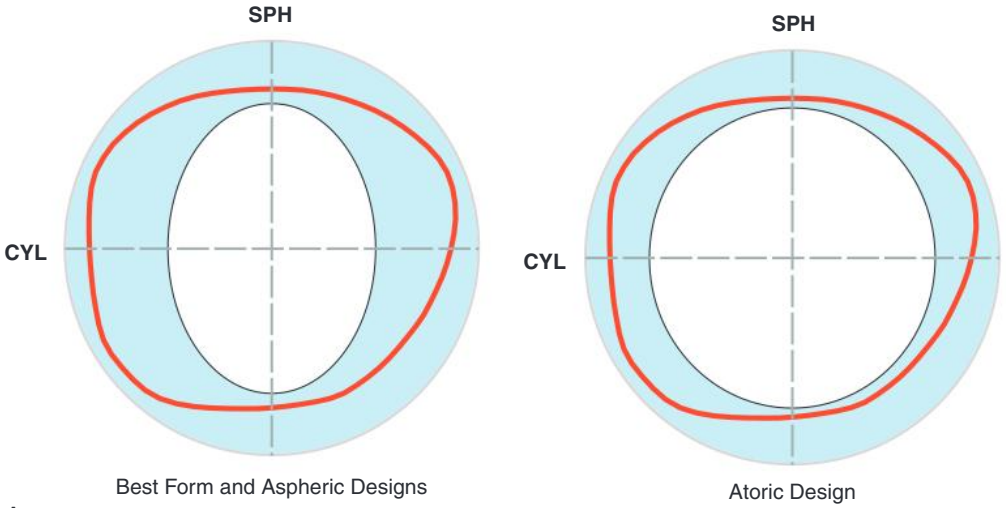
WORKING WITH ASPHERIC AND ATORIC LENSES

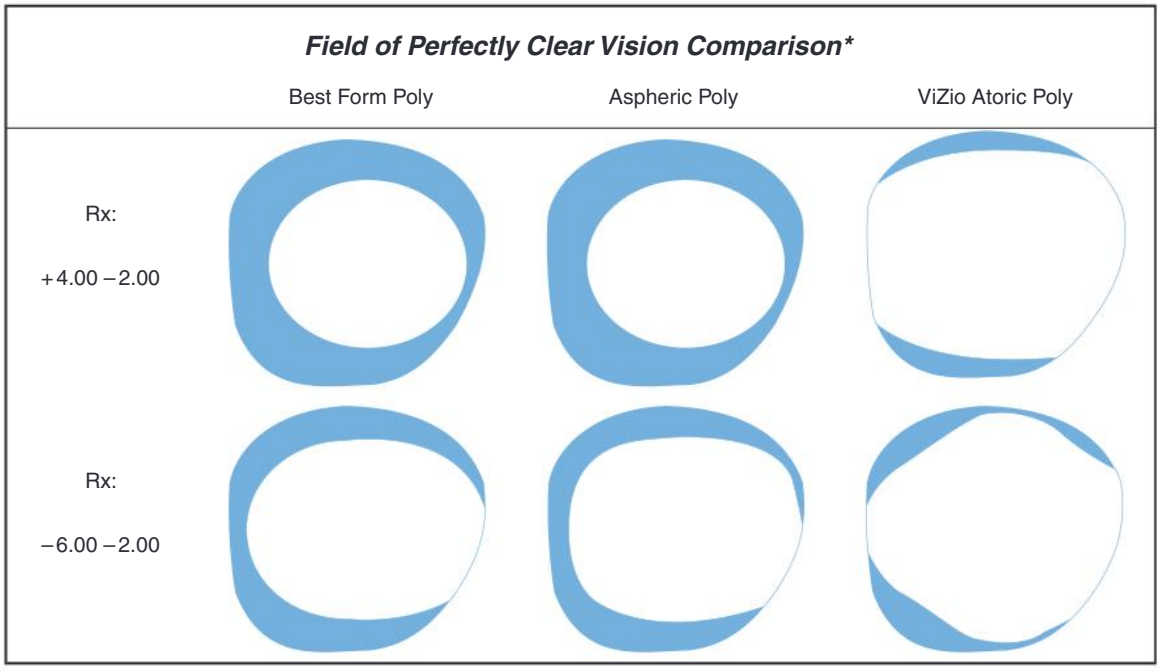
Why Dispensing Rules Take on Special Importance for Aspheric Lenses

A well-designed aspheric lens can produce excellent optical and cosmetic results. There is one thing that must be kept in mind, however. Aspheric lenses are not as forgiving of dispensing errors as regular lenses. If a regular *nonaspheric* lens is fit without adhering to all the proper fitting rules, vision may still be acceptable enough to produce a happy wearer. But if an *aspheric* lens is fit improperly, the lens can end up being optically worse than a regular spherically based lens would have been.

Fitting Guidelines for Aspheric Lenses

Fitting rules for aspheric lenses are no different than careful fitting rules for any other lens. Remember to always use monocular PDs, measure for major reference point (MRP) height, and use the correct amount of pantoscopic tilt.





C

Figure 18.20 **A,** This is a conceptual drawing showing the zone of optimal vision for a best form spheric or an aspheric spherocylinder lens when the design is optimized for the sphere power meridian. The cylinder power represented in this drawing is fairly high. Here, the wider area produced by the sphere meridian happens to fall in the narrower vertical meridian because of cylinder axis orientation. **B,** An atoric lens allows the design to be optimized for both sphere (*SPH*) and cylinder (*CYL*) power meridians, resulting in a larger area of better vision. (**A** and **B**, Courtesy Darryl Meister, Carl Zeiss Vision.) **C,** Here is a comparison of the size of sharp, clear vision for three polycarbonate lenses in best form, aspheric, and atoric forms for two specific spherocylinder lens powers. There is little difference in peripheral lens clarity between the best form (corrected curve) spherically based lens and the aspheric design, assuming that both lenses are fit correctly. Because an atoric lens can correct peripheral aberrations for both astigmatic meridians independently, the atoric design is able to widen the peripheral area of sharp, clear vision. (From Meister D: ViZio the next generation of aspheric lenses, Sola optical publication #000-0139-10460, 10/98.)

Use Monocular Interpupillary Distances

The eye must be horizontally centered in the "concentric aspheric rings" of the lens. Taking monocular PDs will ensure that this happens.

Measure Major Reference Point Heights and Compensate for Pantoscopic Angle

First, measure MRP heights in the conventional manner (see Chapter 5). Then, use the rule of thumb for tilt compensation (i.e., subtract 1 mm of MRP height for each two degrees of pantoscopic tilt). Aspheric areas concentrically surround the lens OC. Therefore, do not move the MRP more than 5 mm below the pupil, even if the rule of thumb for tilt calls for more than 5 mm. Moving the MRP too far downward can cause the peripheral aspheric area to interfere with normal distance vision.

Alternative method for determining major reference point height: tilt the head and measure. An alternative method for finding MRP height is to first tilt the wearer's head back until the frame front is perpendicular to the floor. Next measure MRP height with the subject's head tilted back. (If the frame has a large amount of pantoscopic tilt, remeasure MRP height without tilting the head. The difference in measurement should not exceed 5 mm.) This head-tilt method should give the same results as compensating for pantoscopic tilt and is certainly easier. (See Chapter 5 for more details regarding MRP height.)

Caution: Some laboratories assume that the MRP height specified on the order form places the MRP in front of the eye. Since this is incorrect in the presence of pantoscopic tilt, some laboratories drop the MRP below the ordered amount to compensate for tilt. You will need to know how your laboratory is treating MRP heights.

The guidelines for fitting aspheric lenses are summarized in Box 18.3.

When to Recommend Aspheric Lenses

For Plus Lens Wearers

For plus lenses, an aspheric lens may easily be recommended when the power goes above +3.00 D. However, opinions vary on when to recommend aspheric lenses. Beginning points range from +2.00 D to +4.00 D or even lower. Remember that as frame size increases, the amount of plus power needed before recommending an aspheric lens decreases. The larger the lens, the lower the power will be when aspheric lenses are recommended.

For Minus Lens Wearers

For a minus lens wearer, an aspheric lens may be recommended for powers above −3.00 D. The "minimum" lens power that is recommended continues to drop. Again, differences as to what the lowest power is for recommending a minus aspheric will differ, depending upon frame size and wearer concerns. (Note: If a high-index aspheric lens is being used primarily to thin the lens, it is counterproductive to place such a lens in a frame with a small eye size and narrow vertical dimension if that frame is a nylon-cord frame. Nylon-cord frames need a minimum edge thickness to allow for grooving the edge. Such high-index lenses may end up having to be made thicker anyway because of the nylon-cord frame.)

BOX 18.3 Fitting Guidelines for Aspheric Lenses

1. Use monocular interpupillary distances.
2. Measure major reference point heights in the conventional manner. Then subtract 1 mm for each two degrees of pantoscopic tilt. (The optical center should not be more than 5 mm below the pupil.)

Alternative method for finding major reference point height: First, tilt the wearer's head back until the frame front is perpendicular to the floor. Next, measure the major reference point height in this position. This alternative method should give the same results as compensating for pantoscopic tilt will give.

Aspheric Lenses Are Recommended for Anisometropia

When a person has a difference in power between the left and right eyes that is greater than 2.00 D, there will also be differences in magnification. Aspheric lenses are normally flatter, thinner, and closer to the eyes and will therefore reduce magnification differences.

Other Possibilities for Using Aspheric Lenses

Aspheric lenses may also be recommended for

- children who are sensitive about how their glasses look;
- contact lens wearers so they will not overwear their contacts to avoid wearing thick, ugly spectacle lenses; and
- older wearers to decrease lens weight.

When to Recommend Atoric Lenses

Atoric lenses may be used whenever aspheric lenses would be used. However, atoric lenses may be more expensive and do not need to be chosen instead of aspheric lenses when there is not much cylinder power present in the lens. An atoric lens should be considered instead of an aspheric lens any time the cylinder power is approaching or is greater than 2.00 D. If there is little or no price difference between an aspheric and an atoric lens of the same power and the lens has cylinder, an atoric lens is appropriate.

Adapting to Aspheric and Atoric Lenses

Changing base curve and lessening the amount of distortion a person experiences when switching from a spherically based lens to an aspheric or atoric lens would seem like a good thing—and it is. However, the person who has been wearing lenses with enough power to cause straight lines to appear curved has already made some adaptations. They have mentally been able to correct the distortions caused by the lens. Their mind straightens the optically distorted (curved) line and sees it as straight. Now when a new correcting lens no longer causes straight lines to look curved, the mind tries to compensate as before, and the world takes on an unfamiliar appearance. Until readaptation takes place, nothing looks right. Those being changed from conventional spherically based lenses into aspheric or atoric lenses should be warned about the adaptation time that will be necessary. Once a person is used to wearing aspheric or atoric lenses, they find them much to their liking. (This is assuming that the lens has been carefully measured and fit.)

HIGH PLUS LENS DESIGNS

Before the advent of intraocular lens implants following cataract surgery, high plus lenses were common, and a number of high plus spectacle lens options were developed. Many of these options are still available. Because high plus options are often thought of simply as "cataract lenses," they may not be being used to full advantage. People who need a high plus correction and have never had cataract surgery are still candidates for these special lens designs.

Regular Spheric Lenses

It is possible to use a regular, spherically based lens for a high plus wearer even though the optics are not as good. Sometimes, these lenses are called *full-field lenses* to make them sound better. Actually, any lens that has the prescribed lens power over the whole viewing surface could be described as a full-field lens (Figure 18.21.).

High-Index Aspheric/Atoric Lenses

Whenever possible, it is best to use a high-index aspheric or atoric lens for high plus lens wearers.

Unfortunately, many of the specialty high plus lenses described in the next sections are only available in regular 1.498-index CR-39 lens material because these lenses were designed when CR-39 was the preponderant material. This may change as laboratories become more creative in using free-form generating for less common lens designs.

Lenticular Lenses

A lenticular lens is one that has a central area with the prescribed lens power surrounded by an outside area of little or no power. The central area is called the *aperture*, and the outer area is called the *carrier* (Figure 18.22). The lenticular style was developed for the purpose of thinning the lens. It is like a small, central plus lens that is attached to a thin, plano lens (Figure 18.23).

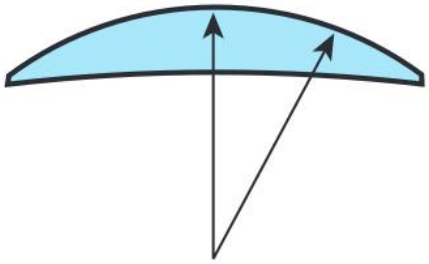


Figure 18.21 This lens has the same radius of curvature over the entire front surface of the lens. A "full-field" lens is one that is optically useable over the entire viewing area. Therefore, technically, even this regular spherically based lens could be called a *full-field lens*.

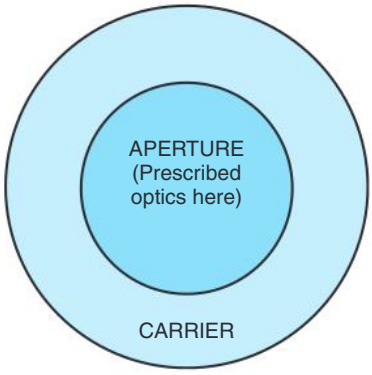


Figure 18.22 When a lenticular lens is viewed from the front, the optically useable central aperture is seen in the center of the outer carrier portion.

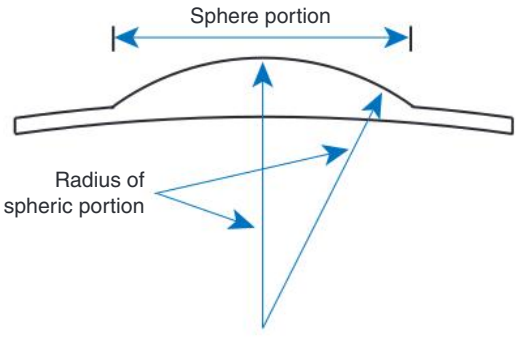


Figure 18.23 The cross section of a spheric lenticular lens shows that the optically useable central portion has the same radius of curvature across its entire surface. The outer carrier portion is considerably flatter.

Lenticular lenses are available as either spheric or aspheric lenticular lenses. *Spheric lenticular lenses* look just like the lens shown in Figure 18.23. *Aspheric lenticular lenses* have an aspheric aperture. An aspheric lenticular lens can be thought of as a small, aspherically designed plus lens that has been placed on a near-plano carrier (Figure 18.24). Of the two lenticular designs, the aspheric lenticular lens is the better choice.

Advantages of a Lenticular Design

The main advantages of the lenticular design are weight reduction, thickness reduction, and, for aspheric lenticular lenses, good optics.

Disadvantages of a Lenticular Design

The main drawback to the lenticular design is looks. Even for small eye sizes, the edge of the aperture is usually visible. If the frame eye size is too large, the lens looks like the yolk of a fried egg.

High Plus Multidrop Lenses

Multidrop lenses started out by choosing cosmetics above optics. The lens dropped in power from the center out to thin the lens and reduced weight, ignoring correction for peripheral aberrations. As the lens developed, the optics of the lens resembled an aspheric lenticular lens but got rid of the unsightly line between the aperture and carrier portions. This was done by rapidly changing the front surface curvature where the two sections met. The central portion of the multidrop lens has an area that resembles the optics of an aspheric lenticular lens. Once outside of this more traditionally designed central area, the front surface suddenly flattens. This allows the outer zone of the lens to function more like a carrier portion. Essentially the lens resembles a large, blended aspheric lenticular lens (Figure 18.25).

HIGH MINUS LENS DESIGNS

The greatest lens problem facing the high minus lens wearer is thick edges. This can be substantially addressed through appropriate frame selection. (For a review of frame selection for high minus lens wearers, see Chapter 4.)

Many of the options for high minus lenses discussed in the following sections may not be needed if the dispenser first applies traditional dispensing principles, such as small effective diameter sizes, high-index lenses, roll and polish, and AR coating. The most common method used by the laboratory for high minus lenses is to put a low minus curve on the front of the lens and a high minus curve on the back. This biconcave lens form is usually accepted by the patient and is less noticeable and less expensive. Yet, if lens power is high enough, these measures may still prove insufficient. If this happens, a special high minus lens design is in order.

Lenticular Minus Designs

A lenticular design for a high minus lens uses the same idea as the lenticular design for high plus lenses. The central area of the lens contains the prescribed refractive power of the lens. The peripheral (carrier) area serves only to extend the physical size of the lens without increasing its thickness.

Lenticular minus lenses can be found in several forms, one of which is the Myodisc. It is important to remember that minus lenticular lens designs are not limited to one type of lens material and can be made of higher index material.

The Myodisc

According to the traditional definition, the Myodisc design has a front surface that is either flat or almost flat. The front usually contains the cylinder component of the prescription. A Myodisc also has a plano

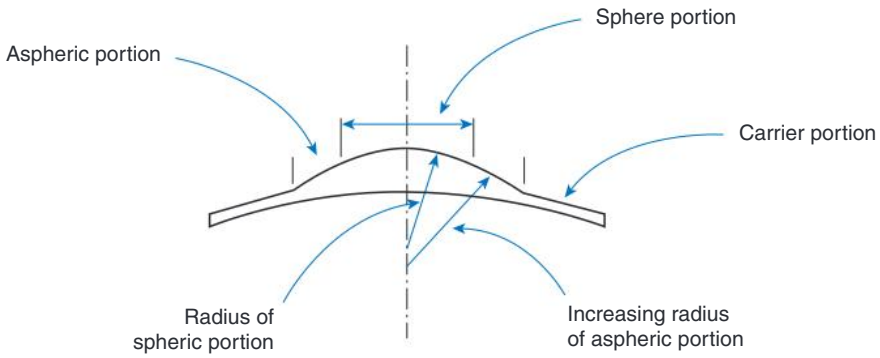


Figure 18.24 The cross section on an aspheric lenticular has a varying radius of curvature across the aperture. There is still an abrupt, visible demarcation between the central aperture and the carrier.

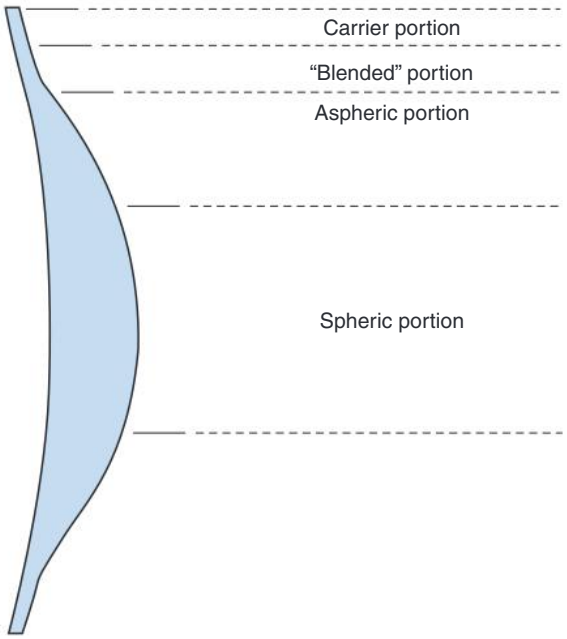


Figure 18.25 A multidrop lens can incorporate the advantages of optically sound aspherics for near-peripheral viewing, plus a fast-changing aspheric drop toward the edge, resulting in what could almost be considered a blended aspheric lenticular lens.

back carrier area. There is a high minus "bowl" in the middle of the back surface. (Originally, these lenses, made from glass, had a small 20- or 30-mm bowl size. Myodisc is a trade name.)

In a Myodisc type of lens, the carrier is near plano. Therefore, the thickness of the carrier portion is constant. The larger the bowl area is, the thicker the carrier will be. For lenses with the same-sized bowl areas, increases in lens power will mean an increase in carrier thickness (Figure 18.26).

Because the Myodisc carrier is plano, as bowl size or lens power increases, edge thickness can become significant. It is conceivable to reduce edge thickness by using a different form of a minus lenticular design. (Note: The name "Myodisc" is often used to refer to any minus lenticular design.)

Minus Lenticular

A high minus lens with a lenticular design can be made so that the carrier is not plano. Several examples of minus lenticular lenses are shown in Figure 18.27.

If the back side of the carrier is made plus, as shown in Figure 18.27, *B* and *D*, the outer edge will thin down considerably. Often the laboratory makes this type of lens by beginning with a semifinished lens that has a plus six or greater front curve. The minus bowl is ground into the "front" of the semifinished lens. This will become the back of the minus lenticular lens. The cylinder and remaining power is ground onto what will become the front of the lens.

MYOPIA CONTROL

There has been a rapid increase in myopia worldwide. Unfortunately, thick-edged minus lenses are not the only resulting problem. Myopia progression leads to high myopia with an accompanying increase in the eye's axial length. This results in increased risk of other serious eye disorders such as retinal tears leading to retinal detachment, glaucoma, cataract, and myopic macular degeneration.[8,9]

Using an intuitive approach, early practitioners often attempted to slow myopia by undercorrecting spectacle lens power. Unfortunately, research has now shown that outcomes resulting from undercorrecting a myopic eye are worse than when the full myopic correction is prescribed. Undercorrection actually may cause an increase in myopia progression.[10]

An alternative spectacle lens approach has been used to prescribe bifocals or progressive addition lenses to slow myopia. Results indicate that myopia was slowed somewhat for children with near-point esophoria[11] and high accommodative lag,[12] but, most often, progression was not effectively slowed. Fortunately, even though previous methods of attempting to slow myopia with conventional spectacle lenses have not been very successful, there are now newer spectacle lens designs that show much greater promise.

A Theory for Myopia Development

Contrary to what might seem logical, instead of the central retina controlling the axial length growth of the eye, the peripheral retina appears to also have significant influence.[13] Traditional lenses result in the central retina being in focus, but, in the periphery, the image is behind the retina (Figure 18.28). (We normally associate a behind-the-retina image with hyperopia.) This is a result of *image shell error*. (The dioptric difference between the place where an image formed in the periphery of the retina focuses and where it should focus is called the *image shell error*.) This *hyperopic error* in the periphery is referred to as *relative peripheral hyperopia*. It is believed the eye responds to this behind-the-retina focus in the periphery by growing longer to meet it. Unfortunately, this increased axial length

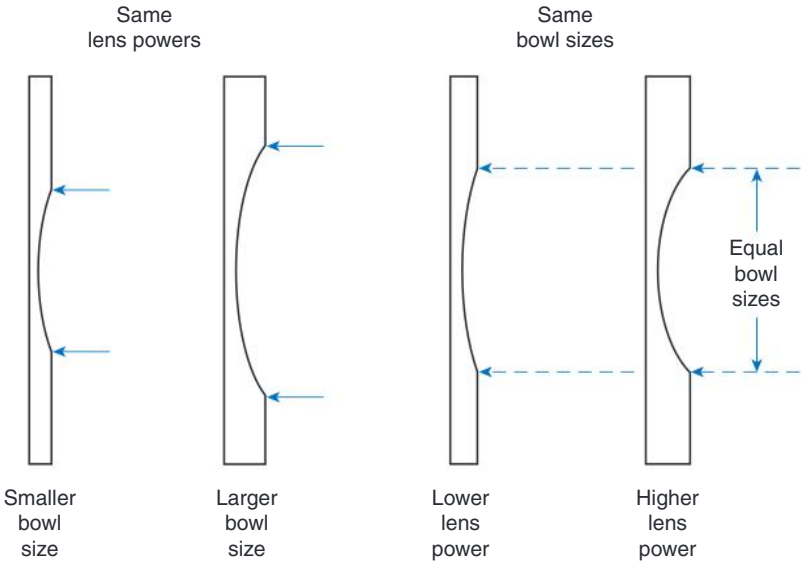


Figure 18.26 For a Myodisc lens (having a plano carrier), edge thickness increases with both lens power and bowl size.

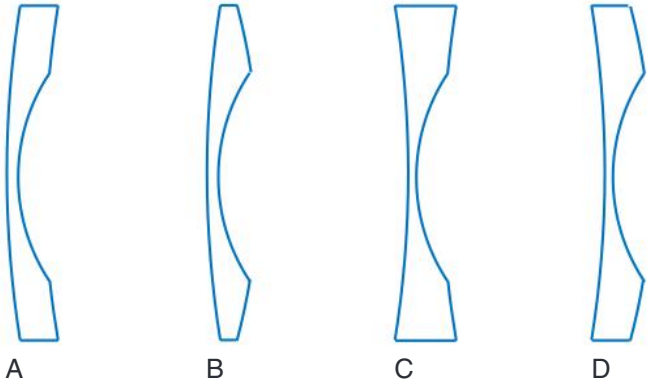


Figure 18.27 Minus lenticular lenses may be made in a variety of forms. Here are some examples. All have a high minus power in the central bowl area. The numbers are for illustration purposes only. **A,** A minus lenticular lens with a −2.00 D back carrier curve and a +2.00 D front curve. **B,** A minus lenticular lens with a +6.00 D back carrier curve and a +2.00 D front curve. The plus 6 back carrier helps to thin the lens edge. **C,** A minus lenticular lens with a −2.00 D back carrier curve and a −2.00 D front curve. The minus front curve increases the total minus power without having to make the back bowl curve even more concave. **D,** A minus lenticular lens with a +6.00 D back carrier curve and a −6.00 D front curve. Again, the plus back carrier helps to thin the lens edge. It would be possible to put a higher plus carrier curve on the back of the lens to obtain more edge thinning.

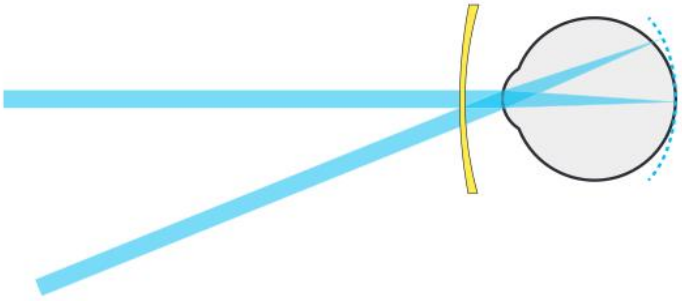


Figure 18.28 Normal corrective lenses bring the central rays in focus to form a clear image. However, peripheral rays focus behind the retina. This hyperopic error creates relative peripheral hyperopia. It is hypothesized that the eye responds to the behind-the-retina focus and grows longer to meet it, creating more myopia.

of the eye moves the central image in front of the retina. The result is even more myopia.

Some of the more successful methods of myopia control make use of lenses that are able to correct vision centrally while bringing rays from objects in the periphery into focus in front of the peripheral retina instead of on or behind the peripheral retina. The following are some general theories of how myopia control is accomplished in spectacle lenses, but this technology is rapidly evolving.

Spectacle Lens Designs for Controlling Myopia

Previously used spectacle lens methods of myopia control, such as undercorrection using single-vision lenses or the use of bifocal or progressive addition lenses, have not been very successful. Therefore, efforts have been made to design spectacle lenses a different way. This has been done by either creating a myopic defocus in the periphery of the retina (Figure 18.29) instead of hyperopic defocus or reducing contrast in the periphery of the lens. The primary advantage for using spectacle lenses is that they are generally well-accepted by parents and children. They are likely to be worn in a consistent and compliant manner.

As with contact lenses, myopia control lenses often must go through a process of approval in countries where they will be sold. This means that new spectacle lens myopia control designs will not be simultaneously available in all countries.

Lenses With Peripherally Placed, Plus-Powered Lenslets

In an effort to shift peripheral focus from behind the retina (relative peripheral hyperopia) to in front of the retina (relative peripheral myopia), a lens with miniature, plus-powered lenslets was created. The initial lens of this type was developed in cooperation with Hoya at The Hong Kong Polytechnic University[14] and is referred to as the *D.I.M.S. (Defocus Incorporated Multiple Segment) lens.* Each lens has about 400 miniature plus-powered lenslets located in the mid-periphery

of a single-vision lens. Each lenslet has a diameter of 1.03 mm and a power of +3.50 D.[15] The centers of the lenslets are only 1.50 mm from each other. In clinical testing, schoolchildren wearing D.I.M.S. lenses had myopia progression reduced by 59% (mean difference − 0.55 ± 0.09 D, $P < 0.0001$) and axial elongation decreased by 60% (mean difference 0.32 ± 0.04 mm, $P < 0.0001$) compared with those wearing single vision lenses. Hoya currently markets this lens under the name MiYOSMART (Figure 18.30).

A variation on this technology designed by Essilor and referred to as the Stellest lens also uses plus-powered lenslets but places them in a concentrically arranged configuration (see Figure 18.31). Although all lenslets are plus-powered, the plus power is said to vary with each concentric ring, creating an aspheric-like power change.[17] The 1021 lenslets are intended to produce a consistent myopic defocus in front of the peripheral retina by controlling the shape of the focal image shell and the distance that focal shell is from the retina.[18]

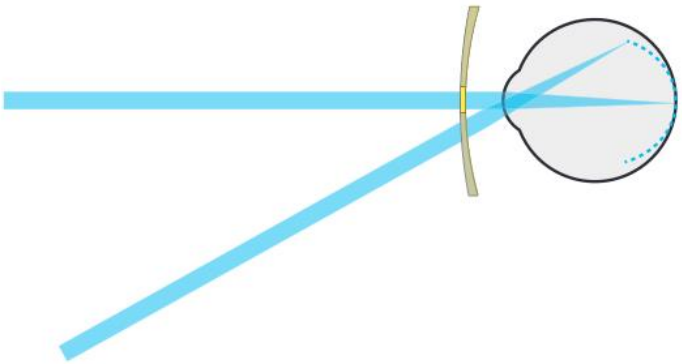


Figure 18.29 If the peripheral lens area of a spectacle lens contains plus-powered lenslets, myopic defocus is created in the peripheral retina. This appears to reduce both axial length growth and dioptric power change, slowing the development of myopia.

Lenses With Peripheral-Contrast–Reducing Dots

The premise behind peripheral-contrast–reducing *light diffusion technology*[19] is that high retinal contrast sends a signal for the eye to grow, but reducing contrast will slow growth of the axial length of the eye.[20] Prescription lenses have a clear central viewing area. The periphery of the lens contains patterns of multiple dots that regulate contrast (Figure 18.32).

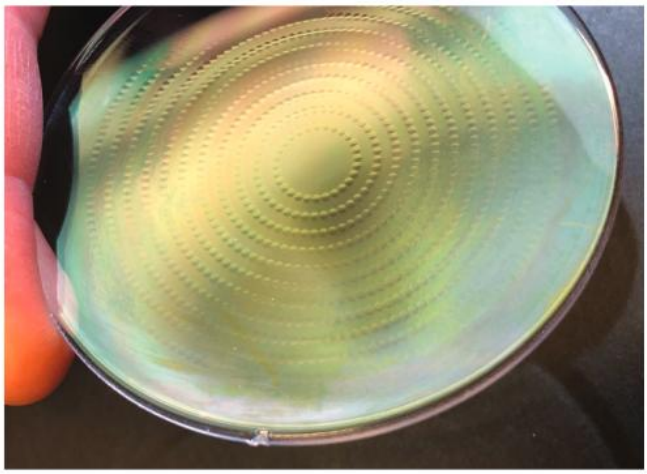


Figure 18.31 At the time of this writing, this Essilor-designed myopia control lens, referred to as the *Stellest*, uses a series of concentric plus-powered lenslets surrounding the correctly determined distance prescription. This photo of the Stellest lens uses illumination designed to show the lenslet pattern. This pattern is not noticeable when worn.

Figure 18.30 The Defocus Incorporated Multiple Segment (D.I.M.S.) lens has about four hundred miniature plus-powered lenslets located in the mid-periphery of a single-vision lens. At the time of this writing, this lens design is marketed by Hoya under the name MiYOSMART (Courtesy Hoya).[16]

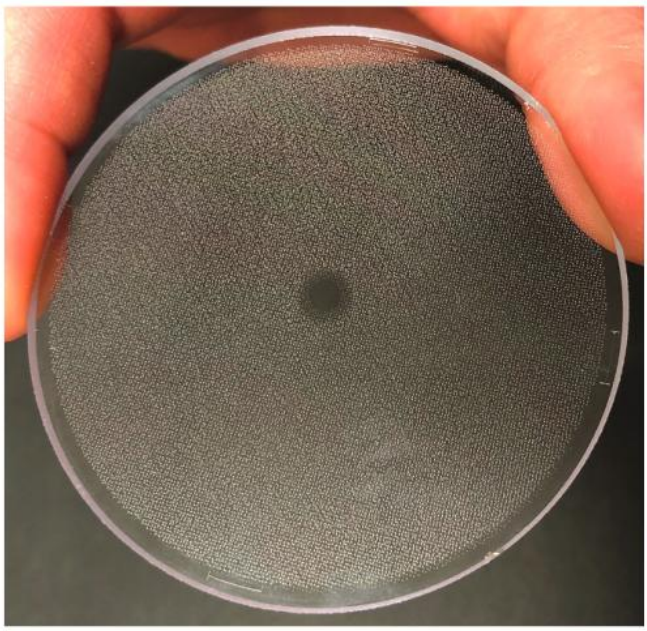


Figure 18.32 This light-diffusing technology lens uses diffusion to reduce peripheral contrast in a noticeable way. Reduction in peripheral contrast slows the progression of myopia.

Initial testing of this type of lens found that a contrast reduction of approximately 60%[21] was not noticeable to the wearer. After a year of testing, the lens showed a 74% slowing in myopia and a 50% reduction in axial length progression.[22]

Fitting Myopia Control Spectacle Lenses

All of the spectacle lens myopia control designs described here have a clear central area surrounded by either plus-powered lenslets or a concentric area that causes reduced contrast. It is therefore imperative that the clear central aperture be positioned in front of the eye. This allows for good central vision while the surrounding periphery can accomplish the desired slowing of myopia progression. One must be certain to accurately measure both monocular PDs and monocular pupil center heights in order for the lens to perform as designed. It is also helpful to explain to wearers how to change their head position as opposed to just their gaze when viewing targets and performing tasks.

Alternatives to Spectacle Lenses

Successful methods show a slowing in the yearly dioptric rate of change, as well as a slowing of axial length growth of the eye when compared with control groups. Here are some of the nonspectacle lens methods that have been successfully used.

Environmental Intervention. Although it proves difficult to establish clear cause and effect results because of so many variables, there does appear to be a relationship between myopia and near work.[23] As a supplement to a program of myopia control, it is common to recommend such things as more outdoor time, less time spent at near work, and intermittent breaks while doing near work.

Low-Dose Atropine. Atropine is simple to use and does slow the progression of myopia. In choosing dose strength, there must be a balance between effectiveness and unwanted side effects. At the time of this writing, low-dose atropine (0.05%)[24] has been used effectively.

Orthokeratology. Orthokeratology for myopia control uses single-vision contact lenses. These lenses are fit flat centrally but steepen peripherally. This corrects the myopia centrally but creates plus power in the lens periphery, allowing peripheral rays to focus in front of the retina. This avoids the peripheral hyperopic shift that is thought to drive axial length growth. This peripherally located "add" effect can also help reduce the demand on accommodation during near work.

Multifocal Contact Lenses. The first soft multifocal lens approved for myopia control in the United States used a central zone corrected for distance vision followed by concentric rings with alternating distance and near power. So the central zone is distance-powered, then comes a near-powered ring, followed by a distance ring, and then another near-powered ring.

There is similarity between the way orthokeratology and multifocal contact lenses work compared with previously described spectacle lens designs.

WEARER-ADJUSTABLE LENSES

What would be the usefulness of spectacle lenses that can be individually "tuned" by the wearer to bring viewed objects into focus? There are a few.

- To make glasses available to areas of the world where eyecare is scarce.
- To temporarily replace someone's prescription eyewear that has been lost or broken.
- To change the entire lens from distance vision to near vision and back again so that the full lens is available for viewing one chosen distance.

Fluid-Filled Lenses

The first lens to gain prominence was developed in 1985 by an Oxford University professor, Joshua Silver, an atomic physicist. He did it by adding or removing water to a membrane lens, causing a change in refractive power. His first application was to develop the spectacles to meet the need for individualized eyeglasses where much of the population had no access to vision care professionals.

Fluid-filled lenses are limited to sphere powers and round shapes. When used alone, the closest a lens can come to a full spherocylinder lens prescription is the spherical equivalent of that prescription. However, fluid-filled lenses can be mounted behind a spherocylinder prescription. For example, the power variation of the fluid lens can then be used to increase the plus power over the whole viewing area of the lens.

Alvarez Lenses

Alvarez lenses consist of two parts, each with a wavelike surface. As the lens parts slide over each other, the power of the two parts combined varies. This is shown in Figure 18.33. In simple terms, each half has both plus and minus surfaces. If the plus part of one is aligned with the minus part of the other, the two powers cancel out and the power is zero. But as the surfaces move in opposite directions, the power will increase in plus power or in minus power, depending upon the direction of movement.

When used for spectacle lenses, the Alvarez lenses are designed to change the sphere power. When used with no other refractive lens, the Alvarez lens may be adjusted to reach the spherical equivalent of a prescription. The Alvarez lens system may be located behind a regular spherocylinder lens. Then, the overall lens power may be gradually increased by the wearer to increase the "add" over the whole surface of the lens. Using the Alvarez system in combination with a progressive addition-style lens,[25] adding minus or plus power using the Alvarez optics can optimize the lens for either distance, intermediate, or near working distance.

Electroactive Lenses

It is possible to apply a tiny electrical current to liquid crystals, causing the refractive index of the material to change. This changes the power of the lens. Electro-optics were successfully developed and brought to the market under the name *emPower*, by Pixel Optics. They were intended to replace conventional segmented and progressive addition lenses to correct for presbyopia. This change could be activated either by tilting the head downward, as to read, or by using a manual mode to change the power. They came with a cradle to charge their batteries overnight. Unfortunately, the glasses did not experience the success required to sustain the product, and it was taken off the market.

It should be assumed that electro-optics will successfully reemerge, as there is ongoing research and development toward that end.

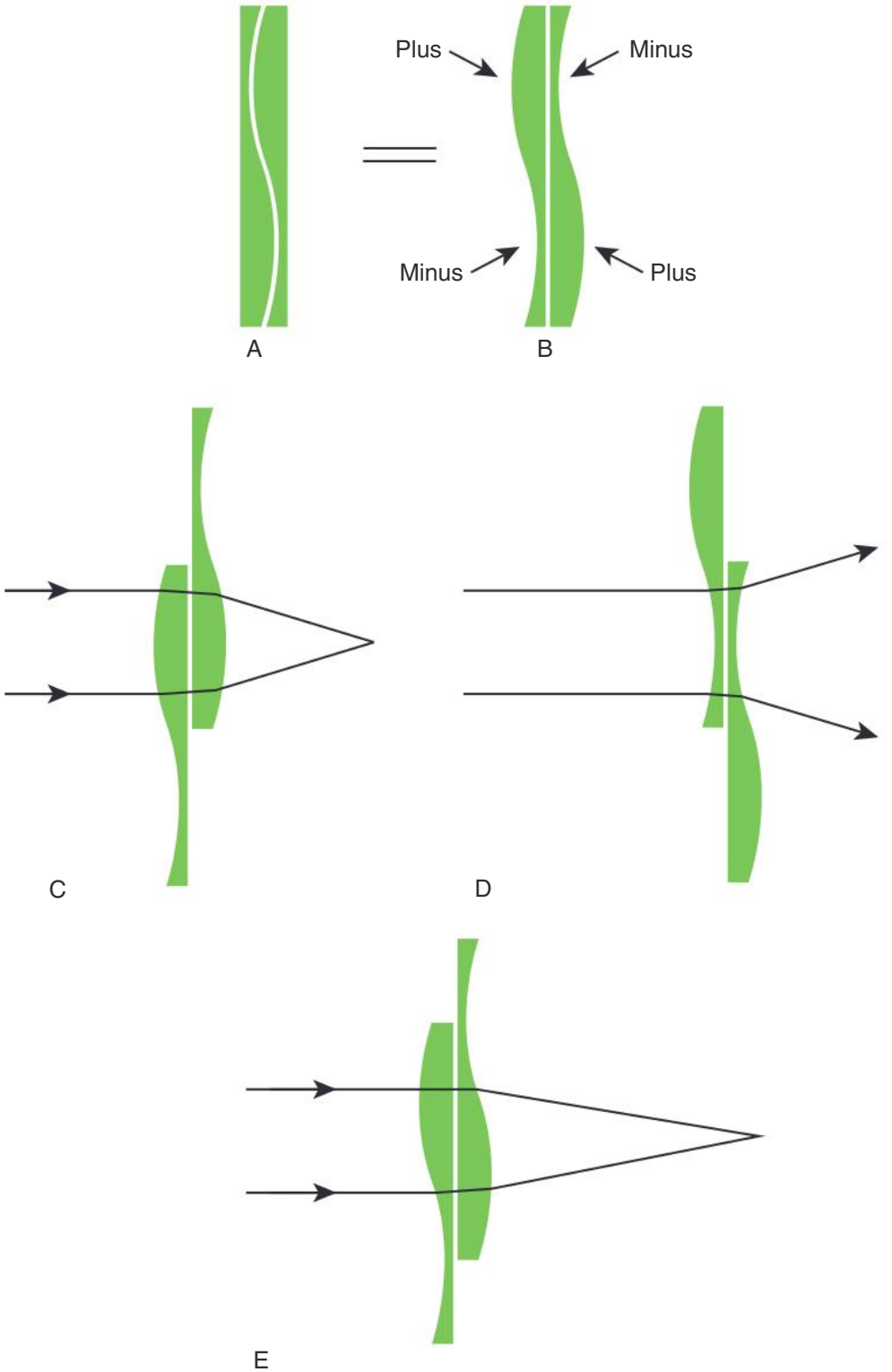


Figure 18.33 Here is a simplified drawing of how an Alvarez lens works. If the two halves of an Alvarez lens are placed with their curved surfaces toward one another, as in **A,** the plus and minus-powered surface curves cancel each other out. The lens has zero power. If the plano surfaces are placed against one another, the outer surfaces are parallel to one another so the lens still has zero power, as in **B.** The lens configurations in **A** and **B** both have zero power. What if the same lens that is shown in **B** has the two halves slid in opposite directions? In **C,** the sections of the lens halves with plus surface powers are both centered and in front of the eye. A maximum plus power will be produced where the lens halves overlap. However, if the lens halves are slid in opposite directions, the minus surfaces are centered and in front of the eye. In the case, maximum minus power will be produced where the lens halves overlap. This is shown in **D.** Between these two extremes, the lens produces powers that are moderately plus or minus in power. Such a situation is shown in **E,** where the lens produces a somewhat weaker plus power.

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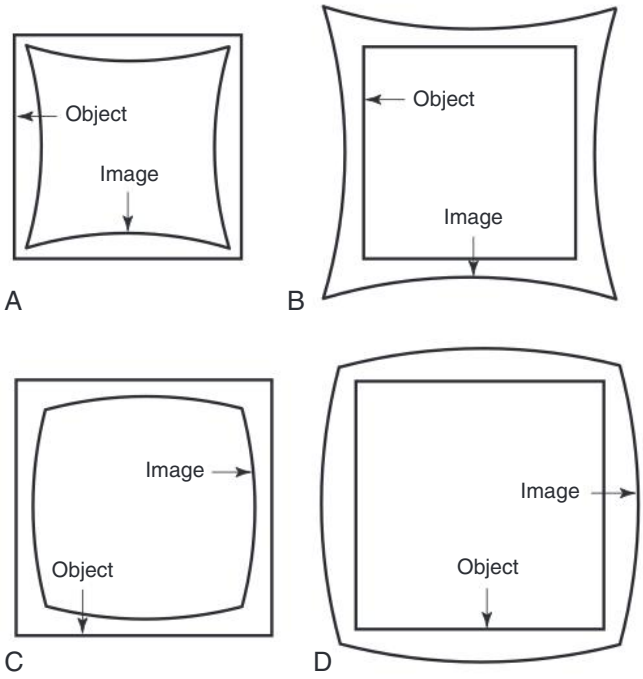
PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. A −7.00 D single-vision polycarbonate lens with no prescribed prism has an index of 1.586 (Abbé value of 30). How much lateral chromatic aberration does the lens have for a point 15 mm below the optical center?
   a. 0.11 Δ
   b. 0.35 Δ
   c. 0.45 Δ
   d. 0.80 Δ
   e. 10.5 Δ
2. True or false? Chromatic aberration may be irritating, but it does not reduce the visual acuity when the wearer looks through the periphery of the lens, regardless of lens power.
   a. True
   b. False
3. A pair of glasses is prescribed with 8Δ of prism base out for each eye. There is no refractive power in the lens—only prism. If visual acuity is 20/20 with no prism, what would the expected visual acuity through these glasses be if using polycarbonate lenses with an Abbé value of 30? (Use Figure 18.3 to answer the question, and choose the closest answer.)
   a. 20/20 (no reduction in visual acuity)
   b. 20/25
   c. 20/30
   d. 20/40
   e. 20/60
4. When comparing these different viewing situations, in which situation would visual acuity be reduced most?
   a. Through the center of a polycarbonate lens having a refractive power of −15.00 D.
   b. At a point 6 mm from the center of a −7.00 D polycarbonate lens.
   c. Through the center of a plano-powered polycarbonate lens with 12.00 Δ of base- out prism.
   d. Visual acuity is not reduced in any of these situations.
5. You read about a new lens. The lens has an Abbé number of 22. What does this tell you?
   a. The lens will be lighter in weight than most.
   b. The lens will have more chromatic aberration than most.
   c. The lens will be heavier than most.
   d. The lens will have less chromatic aberration than most.
   e. The Abbé number has nothing to do with either weight or chromatic aberration.
6. Which lens material has the highest Abbé value?
   a. Trivex
   b. CR-39
   c. Polycarbonate
   d. 1.74 Index plastic
7. True or false? Antireflection coatings will reduce the actual amount of chromatic aberration found in a polycarbonate lens.
   a. True
   b. False

8. True or false? An achromatic lens is used for spectacle lens wear, but only in rare instances when patients experience symptoms of color fringes on print material when reading.
   a. True
   b. False
9. Tscherning's ellipse shows lens design possibilities when choosing:
   a. the overall best lens design when working with spherical lenses.
   b. a Percival form lens.
   c. a Point Focal lens.
   d. a corrected curve lens.
   e. none of the above.
10. A Tscherning's ellipse:
   a. is the same size regardless of working distance.
   b. shows that oblique astigmatism can be brought to zero for one specific viewing distance and peripheral viewing angle by using specific sphere curves.
   c. shows the one lens form per given lens power, which corrects oblique astigmatism.
11. A sphere lens is tilted because the frame it is in has a wrap-around angle of 20 degrees for each lens. What will happen to the induced sphere power of this lens?
   a. If the lens is plus in power, the sphere power will increase in plus power. But if the lens is minus in power, it will decrease in minus power.
   b. If the lens is plus in power, the sphere power will decrease in plus power. But if the lens is minus in power, it will increase in minus power.
   c. If the lens is plus in power, the sphere power will increase in plus power. And if the lens is minus in power, it will increase in minus power.
   d. If the lens is plus in power, the sphere power will decrease in plus power. And if the lens is minus in power, it will decrease in minus power.
   e. It is not possible to predict what will happen to the sphere power of the lens.
12. A plus sphere lens is tilted because the frame has a wrap-around of 20 degrees for each lens. What will happen to the induced cylinder of this lens?
   a. If the lens is plus in power, the induced cylinder will also be plus in power and the axis of the induced cylinder will be axis 180 degrees.
   b. If the lens is plus in power, the induced cylinder will also be plus in power and the axis of the induced cylinder will be axis 090 degrees.
   c. If the lens is plus in power, the induced cylinder will be minus in power and the axis of the induced cylinder will be axis 090 degrees.
   d. There is not enough information given to be able to determine the answer.
13. Most of the time people think that only the power of a lens is being affected with lens tilt, but there is prism induced as well. When a lens prescription in placed in a pair of wrap-around frames, which factor is not needed when figuring the amount of prism induced by the tilt of the lens?
   a. Back vertex lens power.
   b. Angle of tilt (wrap angle).
   c. Lens thickness.
   d. Index of the material.
   e. Base curve.
14. Three "wrap" frames contain lenses with +8.00 D base curves. All three lenses are of equal center thickness, have the same index of refraction, and have the same wrap angle. Which one of the lenses listed has the greatest amount of wrap-angle–induced prism? (Wrap angle and face form are synonyms.)
   a. A −3.25 D lens.
   b. A +2.50 D lens.
   c. A plano lens.
   d. They all would have the same amount of wrap-angle–induced prism.
   e. None of these lenses will induce any unwanted prism because of a wrap angle.
15. A minus lens is manifesting distortion. What does the shape of the image shown in this figure look like compared with that of the original square object? (Only one of the four is correct.)



   a. A
   b. B
   c. C
   d. D
16. A corrected curve lens is
   a. one that corrects for oblique astigmatism.
   b. one that corrects for curvature of field.
   c. one that attempts to reduce both oblique astigmatism and curvature of field.
   d. All of the above are correct responses.
   e. None of the above are correct responses.
17. Choosing from the base curves listed, which would be closest to the expected base curve for a −10.00 D sphere?
   a. +8.00 D
   b. +6.00 D
   c. +4.00 D
   d. +1.00 D

18. A lens has a power of −1.00 −2.00 × 180. Using Vogel's formula, what is the theoretical base curve for this lens?
    a. +1.00
    b. +2.00
    c. +4.00
    d. +5.00
    e. +7.00
19. When lens base curves are properly selected, the further from plano the lens power goes in the plus direction, the _____ the *back* curve of the lens becomes.
    a. steeper (more concave)
    b. flatter (less concave)
20. A CR-39 plastic lens has a base curve of +7.00. Remembering base curve selection principles for spherically based (nonaspheric) lenses, this lens is most likely to be
    a. plus in power.
    b. minus in power.
    c. It is as equally likely to be plus as it is to be minus in power.
21. True or false? A spherically based lens in a certain sphere power will optically give the best results if made on a +6.00 D base curve. This same-powered lens can be made on another base curve such as +4.00 D or +8.00 D as long as it is made as an aspheric lens with the asphericity specifically calculated for the +4.00 D or +8.00 D base curve. It will still give optical results in the periphery of the lens that are just as good as they were for the original +6.00 D base lens.
    a. True
    b. False
22. A wearer has a distance prescription of +3.75 D? Which of the following is *not* a valid reason for choosing an aspheric design?
    a. to produce a thinner lens
    b. to produce a lighter weight lens
    c. to produce a flatter base curve
    d. to produce a lens that results in a better visual acuity through the center of the lens than a spherically based lens of the same power
    e. All of the above are valid reasons for choosing an aspheric lens for this prescription.
23. The outermost area of a lenticular lens is called
    a. the aperture.
    b. the closure.
    c. the carrier.
    d. the cortex.
    e. none of the above.
24. For a true Myodisc design (with flat carrier surfaces), the thickness of the carrier portion increases with
    a. a decrease in bowl diameter.
    b. an increase in bowl diameter.
    c. a decrease in minus lens power when there is no change in bowl size.
25. True or false? All plus-powered lenticular lenses have an aspheric central portion.
    a. True
    b. False
26. True or false? The center thickness of a plus-powered lenticular lens will vary depending upon the effective diameter of the frame and decentration required for the lens.
    a. True
    b. False
27. True or false? Undercorrecting a minus lens wearer whose myopia is becoming increasingly greater is an effective way to control myopia progression.
    a. True
    b. False
28. Which portion of the retina is thought to have the greater influence in the growth of the eye's axial length?
    a. The peripheral retina
    b. The central retina

19

Segmented Multifocal Lenses

MULTIFOCAL LENSES

Multifocal lenses meet the wearer's needs for focusing light at more than one, or *multiple*, distances. Originally, all multifocal lenses had visible segments. There were no progressive addition lenses with gradually changing powers hidden from view. To help distinguish multifocal lenses with progressive optics from multifocal lenses with distinctly different powers in sharply demarcated areas of the lens, the lenses with visible segments may be referred to as *segmented multifocal lenses.*

The Concept of a Near Addition

The crystalline lens within the eye becomes nonelastic because of the aging process. This condition is called *presbyopia*. Because of presbyopia, a person becomes unable to see clearly at close range, regardless of how well vision is corrected for distance. To see clearly at near, the wearer needs additional plus lens power.

Suppose a person has no need for correction of distance vision. If no distance correction is required, the only factor to be considered is the necessary plus lens power to see clearly at near. Also, suppose that the amount of plus power needed for near vision is +2.00 D. This can be given in the form of a regular, single-vision lens having the same +2.00 D power over the whole lens. It can also be given as a lens with no power in the main portion of the lens but with a small area of plus power in the lower portion of the lens as shown in Figure 19.1. This is the concept of a bifocal lens.

However, if the wearer does have a correction for distance, the extra required power for near must be "added on" to the power found in the distance prescription already being worn; hence, the term *near addition*. The near addition is the same as a small plus lens placed in the lower portion of the lens. For that reason, it is often referred to as the *near segment* or, in abbreviated form, the *seg*. The net power resulting from the combination of the distance power and the add power is termed the *near power.*

An example of how the power of the near addition is written in prescription form is

O.D. + 3.25 D sphere
O.S. + 3.25 D sphere
Add: + 2.00 D

By this, it is understood that both lenses are to contain a near segment whose power of +2.00 D adds that much more plus power to that part of the lens.

In the previous example, since an addition is made to the distance power, the measured power through the distance portion of the right lens is +3.25 D sphere, and the measured power through the near portion is +5.25 D sphere (Figure 19.2). In simplified terms, if the near object is at the −50 cm focal point of the +2.00 near addition "lens," the add allows incoming light to enter the distance lens as if it were coming from a distant object. This way light focuses at the same point as it does for distance vision (Figure 19.3).

To go one step further, consider an example of a lens that has both sphere and cylinder power. If a lens has a distance power of +2.00 −0.75 × 180 with a +2.00 D add, then the actual measured power through the near portion will be +4.00 −0.75 × 180. This may be explained with two power crosses as shown in Figure 19.4. When both meridians are added together, the total near power still contains the same cylinder power. Regardless of whether the distance portion is plus or minus in power, the near portion is still the algebraic sum of distance power and near add.

Example 19.1

The distance portion of a lens is a −2.50 D sphere. The near add power is +2.50 D. What is the near power through the segment portion?

Solution

Since the total near power is calculated as

(Distance power) + (Near addition) = (Near power)

then

(−2.50) + (+2.50) = 0.00

The total power through the segment area of the bifocal lens will be zero. Looking at the near power this way, for people with lower minus-powered distance prescriptions, it makes it easier to understand why they are not enthusiastic about going into multifocal lenses. They can do very well just removing their glasses.

The Trifocal Intermediate

Some lenses have an intermediate area between distance and near portions. This area is used for viewing objects that are not at the normal reading distance. Yet what is being looked at is close enough to make clear vision through the distance portion difficult or impossible. The solution for these situations when using segmented multifocal lenses is a *trifocal* lens (Figure 19.5).

In trifocal lenses, the power of the intermediate portion is normally one-half that of the prescribed near add. It is expressed as a percent. Normally, the intermediate portion will be 50% of the near add. Lenses for special intermediate viewing distances may also be obtained, having intermediate powers of 60% of the near addition.

To calculate the expected power through the intermediate portion of a trifocal lens, first the prescribed trifocal percent of the near add is found. For example, suppose a lens having a +2.50 D add has an intermediate power that is +1.25 D greater than the distance power. Since +1.25 D is half of +2.50, the lens has an intermediate power of

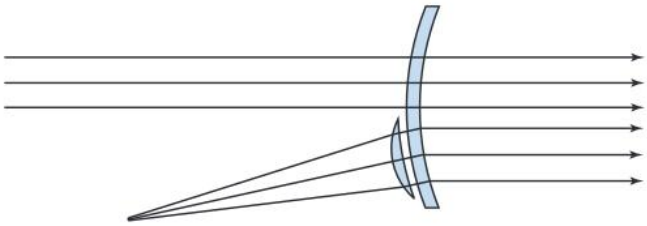


Figure 19.1 A bifocal segment is a small plus lens positioned on a lens that normally corrects for distance vision. Here, the bifocal segment is placed on a lens that has no power in the distance portion.

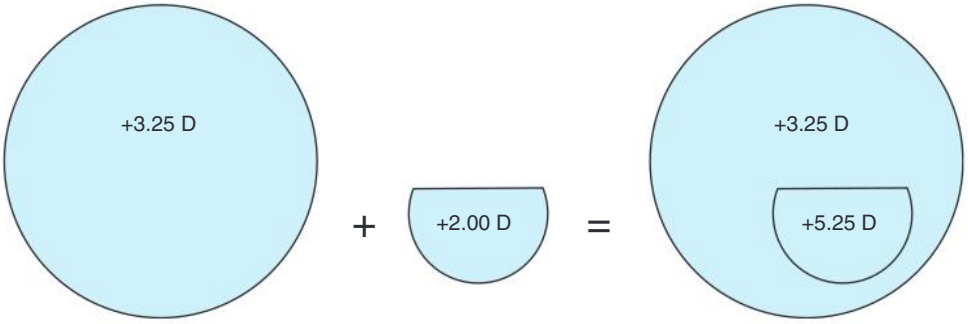


Figure 19.2 A bifocal addition is just that—an addition to the distance power. Here, the distance power of +3.25 D is supplemented with a +2.00 D add for near viewing. The total power at near is +5.25 D. The +5.25 D power is the power that would be used in a pair of single-vision lenses intended to be used only for reading.

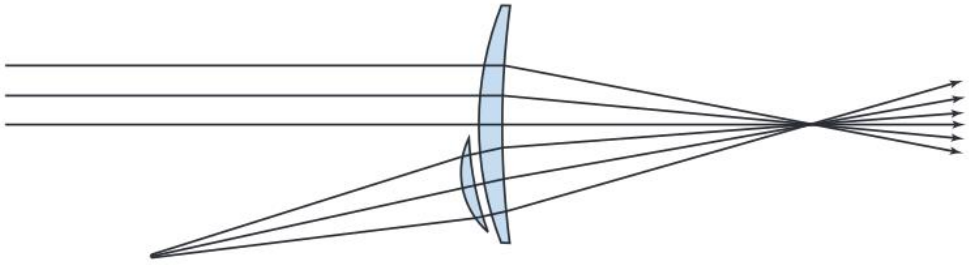


Figure 19.3 A plus lens with a bifocal near addition. (In this figure, the near object is at the primary focal point of the near addition.)

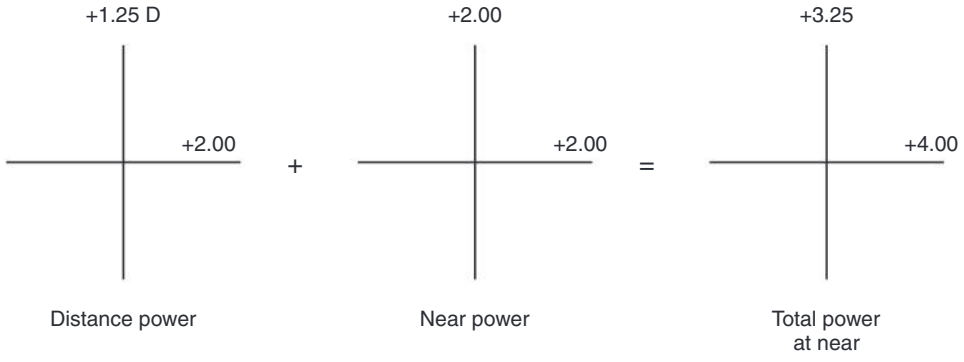


Figure 19.4 The near portion of a lens having an add of +2.00 D does not manifest a +2.00 D power but rather will be the sum of the distance power and near addition combined.

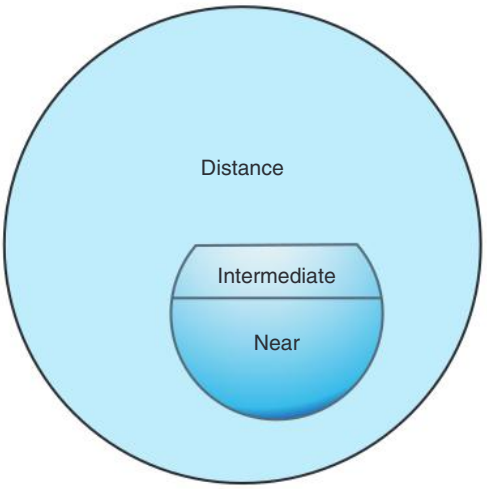


Figure 19.5 A trifocal lens has three viewing areas.

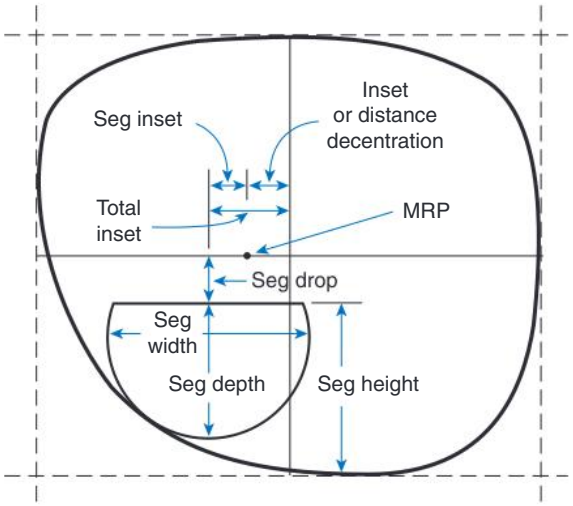


Figure 19.6 The *major reference point (MRP)* of a lens is positioned in the same vertical plane as the pupil and a few millimeters below it. If no prescribed prism is present in the prescription, the MRP and the optical center of the lens are one and the same point. (When prescribed prism is present, the optical center is no longer in the same location as the MRP.) The amount the MRP is moved laterally away from the geometric center of the lens is the *inset* or *outset* (also referred to as *distance decentration*). The additional amount the center of the near segment is moved inward from the MRP is the *seg inset*. The inset plus the seg inset is known as *total inset* (or *total seg inset*).

50%. This +1.25 D intermediate add value is added to the distance power to find the total intermediate power as measured in the lensmeter.

When to Use a Trifocal Lens

Eyes that still have a limited ability to focus and only require a near addition of +1.50 D or less will have clear vision in all intermediate areas of viewing from distance to near. When looking through the upper (distance) part of the lens, the eye can focus on objects at an intermediate distance by using its own focusing ability. This eliminates the need for an intermediate trifocal area. For this reason, most trifocal lenses are not available in add powers below +1.50 D.

After the add power increases above +1.50 D, there will be intermediate areas of vision that are not clear through either the distance portion or the near portion of a normal bifocal lens. To see these areas clearly, the wearer must either look through the upper part of the lens and back away from the object or look through the lower bifocal part of the lens and move closer. A trifocal intermediate will furnish clear vision at this previously blurred in-between distance. (A progressive addition lens will solve this problem as well. For more information on progressive addition lenses, see Chapter 20.)

Terminology

Bifocal lenses are available in a wide variety of segment shapes and sizes from small, round segs to segs that occupy the entire lower half of the spectacle lens. Their size and locations are quantified by means of a few standardized terms.

The horizontal size of a segment, or *seg width*, is measured across the widest section of the segment area (Figure 19.6). If part of the segment area has been cut away in edging the lens for the frame, the dimension is still considered to be the widest portion that the segment had before edging.

The longest vertical dimension of the segment is the *seg depth*. *Seg height* is dependent on the frame for which the lenses have been edged and is measured vertically from the lowest point on the lens to the level of the top of the seg (see Chapter 5). *Seg drop* is the vertical distance between the major reference point of the lens and the top of the segment.

The distance portion of the lens must be decentered from the geometric center of the frame's lens opening so that the locations of the distance optical centers (OCs) will correspond to the wearer's interpupillary distance (PD). This inward decentration is referred to as *inset* and corresponds to what happens when decentering a single-vision lens. For a single-vision lens, inset would usually be called *distance decentration*. For segmented lenses, the segment must be decentered further inward to correspond to the wearer's near PD. This further decentration of the segment is referred to as *seg inset*. The full amount that the segment is decentered is called *total inset*. Total inset is the sum of distance decentration plus seg inset. (Looking at Figure 19.6 should make this easier to understand.)

$$\text{Inset (or outset)} + \text{Seg inset} = \text{Total inset}$$

(Note: If the wearer's PD is greater than the frame's A + DBL, the lens OC is decentered temporally. This outward decentration of the distance OC is called *outset*. Outset would be written as a negative number.)

How Multifocal Lenses Are Constructed

Bifocal and trifocal lenses are usually constructed in three main ways: fused, one piece, and cemented (shown in cross section in Figure 19.7).

1. *Fused*—Fused multifocal lenses are available only in glass. The segment of the lens is made from glass, having a higher refractive index than that of the distance "carrier" lens. (The distance lens is called the "carrier" lens because it is the portion to which the multifocal segment is attached. The segment is carried by the distance portion.) A fused glass bifocal lens has neither a ledge nor a change of curvature on the front of the segment. The segment cannot be felt because it is fused into the distance portion.
2. *One piece*—One-piece multifocal lenses are made from one lens material. Any change in power in the segment portion of the lens is due to a change in the surface curvature of the lens segment. One-piece multifocal lenses can be identified by feeling the segment border. If either a ledge or a change in curvature is felt, the lens is not fused and is a one-piece design.

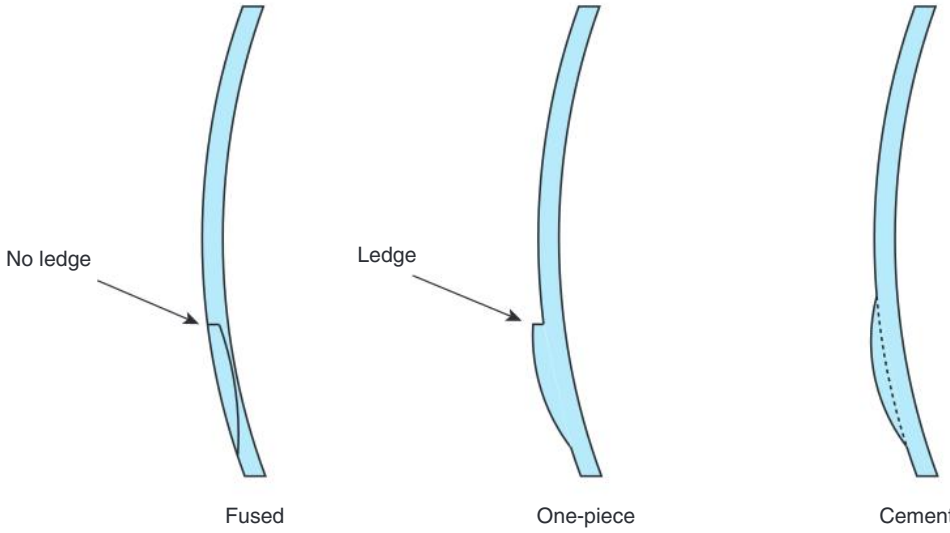


Figure 19.7 A fused segment lens as shown on the left is made using glass that has a higher index of refraction in the segment than in the main part of the lens. One-piece lenses have a ledge that can be felt and may be made from almost any lens material. Cement segs are made by gluing a single-vision distance lens and a small, segment-sized lens together.

One-piece multifocal lenses may be made from any lens material. All plastic lenses are made as one-piece multifocal lenses. One-piece glass multifocal lenses are usually either the full-segment Franklin-style lens with the near portion occupying the entire lower portion of the lens, or they are large round-segment lenses.

3. *Cement lenses*—Cement lenses are custom-made lenses that have a small segment glued onto the distance lens. Used only for specialized custom purposes, such lenses are usually made using small, round segments.

Another occasionally used segmented lens is one that is two lens sections glued together. The upper half is a distance lens, and the lower half is a near lens. Both are cut in half, and half of each is used. The most common application for such lenses is for creating horizontal prism in the near portion only.

TYPES OF BIFOCAL SEGMENTS

There are a few major groupings of bifocal segment styles but many variations within those styles (Figure 19.8 and Table 19.1). The basic styles include round segments, flat-top segments, curve-top segments, and Franklin-style, or Executive, segments.

Round Segments

Round segments vary in size from a small lens of 22 mm up to the largest, 40 mm. The most common sizes are 22 and 25 mm. For large, round seg sizes, on rare occasions, a 38-mm segment might be used. Logically, the OC of a round segment is always at the center of the segment. The round-segment lens is a versatile lens because the round segment can be rotated and still not look tilted. It can also be positioned at odd locations on the lens, such as in the upper temporal corner of a golfer's right lens. (Assuming, of course, that the golfer is right handed.) This keeps the segment out of the golfer's way and still allows access to a near add for score card marking and reading. (This is certainly not the only option for golfers. Other options are used more often.)

Blended bifocal lenses are like round-segment bifocal lenses but with the border of the segment smoothed out to keep the segment from being seen.

Flat-Top Segments

Flat-top segments are basically round segments with the top cut off. The top is generally "cut off" 4.5 to 5.0 mm above the center of the segment. Stated another way, the segment OC is about 5 mm below the seg line. This allows the lens segment to have maximum reading width in the area where most people will be reading. Very wide flat tops have the

Figure 19.8 A sampling of available bifocal segment types.

TABLE 19.1 Bifocal Lenses

General Style	Segment Name or Abbreviation	Segment Width (mm)	Location of Seg OC (mm)	Comments
Flat-top	FT, straight-top (ST), or D style segment	25 28 35 40 45	5 below 5 below 4.5 below On line On line	The flat top is the most commonly used bifocal style
Curve-top	CT	22 25 28 40	4.5 below	The curved top lens is basically of the same design as a flat top segment except that the upper seg line is curved. Curved top lenses are more common outside North America
Franklin	Executive E-Line Full seg	Full width of the lens	On the bifocal line	The top of the segment is a straight line that goes the width of the lens. The segment occupies the entire bottom half of the lens
Round	Round seg	22 24 25	Segment OCs are at the center of the segment.	Round segments have the largest amount of image jump compared to other segment styles having equal add powers
Blended bifocal	Often called invisible bifocals, these lenses are sometimes confused with progressive addition lenses	Generally available from 22 to 28 mm. A patented design is available allowing customizable segment sizes from 15 to 45 mm in width[1]	Segment OCs are at the center of the segment	A blended segment is a one-piece, round segment with the bifocal demarcation line smoothed away

This table is not meant to be an all-inclusive list of available segmented bifocal lenses. There are other, lesser used bifocal segment sizes and styles available. Even those listed here may vary in their availability as segmented lenses are affected by changes in demand and manufacturing.
A note about segment optical center locations: Segment optical center locations are used to compute image jump and to figure vertical imbalance corrections when using dissimilar segments. These locations may be readily remembered as follows:

- Flat-top lenses with segments 35 mm and smaller, as well as curved tops, may be generalized as having their segment optical centers 5 mm below the line.
- Flat-top lenses with segments larger than 35 mm and Franklin-style (Executive) lenses have their segment optical center located on the line.
- Round segments and blended bifocal lenses have their segment optical centers in the middle of the segment. Divide the segment size by 2 in order to find how far below the segment top the segment optical center is located.

segment OC on the line and resemble a large coin cut in half. Flat tops are also known as *D segs*.

Flat tops are the mainstay of lined multifocal lenses. Segment sizes may range from 22 mm up to 45 mm. The vast majority of flat-top lenses currently used are 28 mm or greater.

Curve-Top Segments

Curve-top segments look similar to flat-top segments, except that the upper line is arched rather than flat. There is a distinct point on either corner.

Franklin-Style (Executive) Segments

Franklin-style lenses are more commonly known by the trade name, *Executive*. They are one-piece lenses with the segment extending the full width of the lens. The lens has the advantage of a very wide near-viewing area.

There are some notable disadvantages to this lens. As the add power increases, the segment ledge gets bigger and more unsightly. Because the thickness of the lens is dependent on both the near power and the distance power rather than just the distance power, the whole lens is thicker than a flat-top lens would be. Thickness increases with each increase in add power, making the lens progressively heavier. (Note: It is possible to thin the lens by using yoked base-down prism. This principle is used for progressive addition lenses and is explained in Chapter 20.)

The Franklin-style bifocal lens has the segment OC on the segment line. For this reason, some have referred to these lenses as "monocentric" bifocal lenses. However, a monocentric bifocal lens is one in which the distance and segment OCs occupy exactly the same spot on the lens. It *is* possible for an Executive lens to be monocentric but only if the lens is surfaced so that the distance OC is on the bifocal line at the same location where the segment OC is found. This would not be expected to happen using today's surfacing practices.

If Executive lenses are used, it is important to avoid large eye sizes and large effective diameters. A better alternative to the Franklin-style lens for someone desiring a segmented multifocal lens with a large bifocal reading area is a large flat-top lens, such as a flat-top 35. A large flat-top lens will reduce weight and thickness but still allow a wide near field of view.

The Executive lens is quickly falling out of use and will likely soon reach extinction.

TYPES OF TRIFOCAL LENSES

Most bifocal styles of lenses are also available in a corresponding trifocal style. Trifocal lenses offer the convenience of intermediate vision with a moderately large intermediate field of view (Figure 19.9 and Table 19.2).

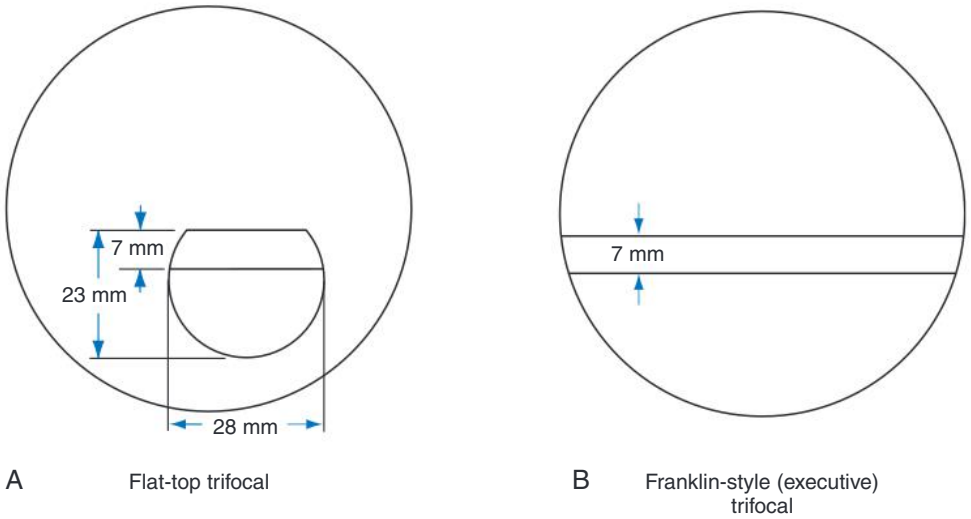


Figure 19.9 **A–B,** Two selected styles of trifocal lenses—the flat-top and the Franklin styles.

TABLE 19.2 Trifocal Lenses

Style	Segment Dimensions (mm)	Comments
Flat-top	7 × 25 7 × 28 7 × 35	The first number in the segment designation refers to the depth of the intermediate; the second number refers to the overall width of the segment. Trifocal lenses have now been largely replaced by progressive addition lenses
Curved-top	7 × 28	Curved-top trifocal lenses are available but are more commonly used outside of North America
Franklin style (Executive)	7-mm Intermediate	These are rarely seen

This is not an all-inclusive list of available segmented trifocal lenses. Even those listed here may vary in availability. Like bifocal lenses, trifocal lenses are subject to variations in demand and availability.

Flat-Top Trifocal Lenses

Flat-top trifocal lenses come with intermediate sections that are commonly found in widths from 25 mm to 35 mm. The most common intermediate depth is 7 mm but, for specialized lenses, depth may reach 14 mm (see Figure 19.9, *A*).

Any trifocal lens that has a depth of more than 8 mm should not be considered a full-time–wear lens. Such lenses are better for occupational situations requiring a large intermediate working area. Occupational trifocal lenses are also available with intermediate powers other than the standard 50% intermediate.

Franklin-Style (Executive) Trifocal Lenses

The Executive, or Franklin-style, trifocal lens is a full-width segment lens with a 7-mm deep intermediate (see Figure 19.9, *B*). It suffers from the same problems as the Franklin-style bifocal lens and, because of the very visible twin ledges, loudly announces the wearer's need for an age-related lens correction.

OCCUPATIONAL MULTIFOCAL LENSES

Any lens that is chosen by careful forethought and positioned for a specialized viewing situation may be classified as an occupational lens. However, there are certain lens styles that are specifically designed with certain work circumstances in mind. These lenses are called *occupational multifocal lenses.*

Trifocal lenses with intermediate segment areas that are vertically larger than 7 mm or with an intermediate power other than 50% of the near add power, such as a 60% intermediate, are considered to be occupational lenses.

Double-Segment Lenses

Some people have occupations that may benefit from an intermediate or near-viewing correction while looking upward. These could include plumbers, pharmacists, librarians, electricians, auto mechanics, and many others in specialized working situations. Double-segment lenses were developed with these types of individuals in mind. Double-segment lenses have a segment in the normal position and a second segment at the top of the lens (Figure 19.10). The two segments are commonly separated by a 13- or 14-mm vertical distance.

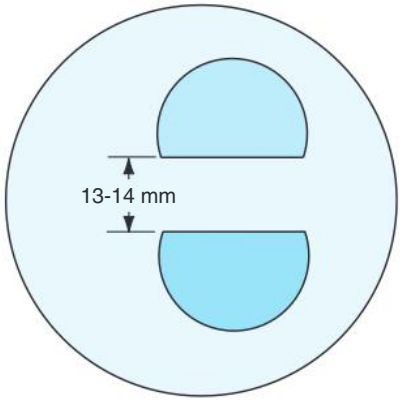


Figure 19.10 An example of a double-segment occupational lens shown in a flat-top style.

Double-segment lenses are underutilized. There are a great many people who would benefit from being able to see at close range just by looking up through an upper segment area. Instead, they are required to tilt their head back in a very uncomfortable position for long periods of time because no one has told them that there is a lens that could solve their neck problems.

The most common double-segment lens is one having an upper segment with a power that is ½ D less than the lower segment power. (For information on how to measure segment heights for double-segment lenses, see Chapter 5.)

Double-segment lenses are most commonly seen as flat tops, such as the double D. They may also be available with round or Franklin-style double segments.

Another double-segment lens that has largely fallen into disuse is called the *quadrafocal lens*. This glass lens has a trifocal segment in the lower portion and an inverted flat-top segment in the upper portion of the lens. Its demise should not be surprising because it is glass and because trifocal lenses have been displaced in great measure by progressive addition lenses. It should be noted that it is possible for a lab to create an alternative to the quadrafocal lens. It is done by starting with a front-surface, plastic, flat-top semifinished bifocal lens. The lens is turned so that the segment is at the top. Then, using free-form surfacing, a progressive addition surface is ground on the back of the lens. The result is a lens that can fulfill the same occupational purpose as a quadrafocal lens. Such a lens could also be a viable alternative to the double-D lens for people who are already wearing progressive addition lenses.

Solving Specialized Viewing Needs With Conventional Segmented Multifocal Lenses

A specialized viewing need may be one that requires correction for two viewing distances, neither of which is for distance vision. For example, if a person has a computer monitor located at an intermediate distance and must also read other material at a 40-cm viewing distance, a regular bifocal could be used with intermediate power in the upper portion of the lens and near power through the bifocal segment. Situations such as this are discussed in the following sections.

Eye care practitioners are only limited in their ability to solve specialized viewing needs by their own imaginations and creative abilities.

For more about occupational lenses, see Chapter 20 on *Progressive Addition Lenses.*

ORDERING THE CORRECT LENS POWER FOR READING GLASSES

When a spectacle lens prescription is written with an add power, it is often written before a decision is made on what type of lenses are to be used. This means that the prescription may have to be written in a different form when ordered so that the same optical effect is maintained. For example, if an individual wants reading glasses only, the order will not be written with an add but will be written for single-vision lenses.

Example 19.2

A prescription is written as follows:

$$+0.25 - 0.50 \times 180$$
$$+0.25 - 0.50 \times 180$$
$$\text{Add}: +1.50$$

The wearer decides they do not want anything but single-vision reading glasses. What power would be ordered?

Solution

The power ordered for reading glasses must be the same as would be found through the bifocal segment. Earlier in this chapter, we stated that:

$$(\text{Distance power}) + (\text{Near addition}) = (\text{Near power})$$

Since reading glasses must be made for the near power, in this example, the near power is figured by adding the add power to the sphere power of the distance prescription.

$$\begin{array}{r} +0.25 - 0.50 \times 180 \\ +1.50 \\ \hline +1.75 - 0.50 \times 180 \end{array}$$

A common mistake is to simply order +1.50 D sphere for reading. The needed near power is really +1.50 D sphere *in addition to* the distance prescription. The add power must be *added to* the sphere power contained in the distance prescription to create the correct power for reading glasses. Astigmatism is still present in the eye regardless of whether distant or near objects are viewed. This requires that the cylinder power be included.

Ordering the Correct Lens Power for Intermediate and Near Only

Certain individuals work in circumstances in which they need a correction for intermediate and near-viewing distances. They see well enough in the distance without a correction. It is as if they need only the intermediate and near-viewing powers of a trifocal lens (Figure 19.11).

Example 19.3

A prescription reads as follows:

$$\text{R}: +0.25 - 0.25 \times 170$$
$$\text{L}: +0.25 - 0.25 \times 010$$
$$\text{Add}: +2.50$$

The wearer has half-eye frames, is satisfied with them, and is not interested in a distance prescription. However, there is a need to see at intermediate distances. The decision is made to place a bifocal lens in the half-eye frame. What power lenses should be ordered?

Solution

To find the new "distance" power, we need to know what the power of the lenses through the intermediate area of a regular trifocal lens in this prescription would be. To do this, we must first know the "intermediate add."

A normal intermediate power is 50% of the near addition. Half, or 50%, of the +2.50 near addition, is:

$$\frac{+2.50}{2} = +1.25$$

Therefore, the top of the new half-eye bifocal lens must be the wearer's original distance power plus the addition in the intermediate or +1.25 D. For the right eye, this is

$$\begin{array}{r} +0.25 - 0.25 \times 170 \\ +1.25 \\ \hline +1.50 - 0.25 \times 170 \end{array}$$

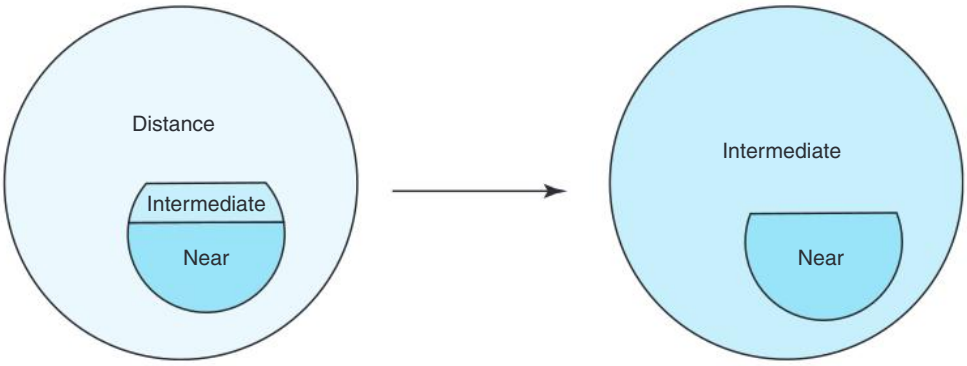


Figure 19.11 If a segmented bifocal lens is to be used for intermediate and near viewing only, the intermediate power normally found in a trifocal intermediate section moves up to where the distance power would normally have been found in a bifocal lens. This will change how the lens must be ordered. Not only does the power in the upper section of the lens change, but even the add power changes. This is necessary so that the power through the bifocal area will remain as intended for near viewing.

and for the left eye

$$\begin{array}{r} +0.25 - 0.25 \times 010 \\ \underline{+1.25} \\ +1.50 - 0.25 \times 010 \end{array}$$

These are the powers of the new "distance" portions of the lenses.

The near portion of the half-eye bifocal lens must read the same in the lensmeter as a regular bifocal lens would have read if it had been made in the original prescription. In the original prescription, the near power for the right eye is

$$\begin{array}{r} (\text{Distance power}) \\ \underline{+(\text{Near addition})} \\ = (\text{Near power}) \end{array}$$

or

$$\begin{array}{r} +0.25 - 0.25 \times 010 \\ \underline{+2.50} \\ +2.75 - 0.25 \times 170 \end{array}$$

So, through the lensmeter, the near power must read: +1.75 − 0.25 × 170.

If

$$(\text{Distance power}) + (\text{Near addition}) = (\text{Near power})$$

then we know by transformation that

$$(\text{Near addition}) = (\text{Near power}) - (\text{Distance power})$$

This can be written as

$$\begin{array}{r} (\text{Near power}) \\ \underline{-(\text{Distance power})} \\ = (\text{Near addition}) \end{array}$$

So the add power is

$$\begin{array}{r} (+2.75 - 0.25 \times 170) \\ \underline{-(+1.50 - 0.25 \times 170)} \\ +1.25 \text{ add} \end{array}$$

Therefore, the half-eye bifocal lens must be ordered as

$$\begin{array}{c} +1.50 - 0.25 \times 170 \\ +1.50 - 0.25 \times 010 \\ \text{Add}: +1.25 \end{array}$$

When ordered like this, the lens powers come out the same as they would have in the original prescription.

Example 19.4

After wearing a new pair of trifocal lenses for a while, the individual returns saying that the trifocal lenses are acceptable but do not have enough reading space through the intermediate area. Instead, they want a pair of bifocal lenses just to wear at work. The strength through the top of a new bifocal lens should be the same as the existing trifocal intermediate. They do like the size and strength of the near portion and want it left as is. Their current prescription reads

$$\begin{array}{c} -2.50 - 1.25 \times 160 \\ -2.50 - 1.25 \times 015 \\ \text{Add}: +2.25 \end{array}$$

Another pair of frames is chosen, and bifocal heights are measured. What powers should be ordered for the new lenses?

Solution

First, determine the power through the present trifocal intermediate area. This could be done with a lensmeter but is better accomplished by looking at the written prescription. Assuming that the intermediate is 50%, or half, of the add power, the "intermediate add" will be

$$\frac{+2.25}{2} = +1.12$$

The power of the new "distance" portion will be the power through the old intermediate. Power through the old intermediate for the right eye is the wearer's distance power plus the intermediate addition.

$$\begin{array}{r} -2.50 - 1.25 \times 160 \\ \underline{+1.12} \\ -1.37 - 1.25 \times 160 \end{array}$$

and for the left eye

$$\begin{array}{r} -2.50 - 1.25 \times 015 \\ \underline{+1.12} \\ -1.37 - 1.25 \times 015 \end{array}$$

To stay with the nearest quarter diopter, we must change the −1.37 sphere power to either −1.50 or −1.25. We choose to round up so that the new "distance" prescription for the right eye will be −1.50 −1.25 × 160.

Next, we need to know the near power of the prescription so that we can determine the add power for the new glasses. In the original prescription, the near power for the right eye is

$$\begin{array}{r}\text{(Distance power)}\\ +\text{(Near addition)}\\ \hline =\text{(Near power)}\end{array}$$

or

$$\begin{array}{r}-2.50-1.25\times 160\\ +2.25\\ \hline -0.25-1.25\times 160\end{array}$$

So through the lensmeter, the near power must read: $-0.25 -1.25 \times 160$.

Since

$$\begin{array}{r}\text{(Near power)}\\ -\text{(Distance power)}\\ \hline =\text{(Near addition)}\end{array}$$

the new add power is

$$\begin{array}{r}(-0.25-1.25\times 160)\\ -(-1.50-1.25\times 160)\\ \hline +1.25\text{ add}\end{array}$$

Therefore, the bifocal lenses must be ordered as

$$\begin{aligned}&\text{R}:-1.50-1.25\times 160\\ &\text{L}:-1.50-1.25\times 015\\ &\text{Add}:+1.25\end{aligned}$$

(Note: If we had chosen -1.25 -125×160 for the "distance" power when we rounded, the add power would have been +1.00 D.)

As demonstrated in the previous examples, to maintain the intent of the prescription, it is sometimes necessary to change the powers of the lenses. Using these examples as a beginning, it is possible to see how specialized eyeglasses can be designed to suit specific needs while maintaining the intent of the original prescription.

IMAGE JUMP

The segment portion of a bifocal lens is like a mini-lens. It has the same characteristics as a normal single-vision lens, except it is smaller. The bifocal section is really a smaller lens that is placed on a larger lens. When the segment is round, the segment's OC will be exactly in the middle of the segment (Figure 19.12, *A*). For example, if the segment is 22 mm round, the seg OC will be 11 mm from the top of the seg.

However, not all segs are round. Some are shaped with the upper section cut off so that the upper dividing line is closer to the OC of the seg (see Figure 19.12, *B*). It is also possible to have a segment constructed such that the OC is exactly on the upper line (see Figure 19.12, *C*). The style of segment chosen depends on the wearer's occupational visual requirement.

One noticeable side effect of segment shape happens as a result of the position of the segment OC compared with the location of the upper edge of the segment. The farther from the segment OC the eye views, the greater will be the prismatic effect caused by the segment.

When wearers drop their eyes while wearing single-vision lenses, prismatic effect increases as the eyes travel downward. However, if the lens is a bifocal, the segment also contains a prismatic effect. (Remember, the segment is really like a mini-lens placed onto another lens.) The value of the prismatic effect caused by the segment is dependent on the location of the segment OC. When the eye crosses the upper border of the segment, the prism induced by the distance portion is suddenly changed by the amount of prism induced by the segment. This abrupt change in prismatic effect causes objects to be suddenly displaced.

This sudden displacement of the image as the bifocal line is crossed is known as *image jump*. The amount of image jump for a given style of bifocal lens is independent of the power in the distance portion. It is caused only by the segment and depends on the add power of the seg and the distance from the segment OC to the top border of the segment. The amount of jump is calculated using Prentice's rule.

Example 19.5

How much image jump does a bifocal lens with a 22-mm round segment have if the add is +2.00 D?

Solution

Since the segment is round with the seg optical center (OC) in the middle, the upper bifocal border is 11 mm above that center. When looking through a point 11 mm above the OC of a +2.00 D lens, a prismatic effect is created equal to

$$\Delta = cF = (1.1)(2.00) = 2.20\,\text{Base down}$$

Therefore, a 22-mm round seg of +2.00 D add power has an image jump of 2.20Δ. The base direction caused by the segment is base down because the eye enters the segment at a location above the segment OC. Because the prism base direction is down, the image is displaced up.

(Note: When the segment is in the lower part of the lens, the direction of the image jump is upward. This is because the eye

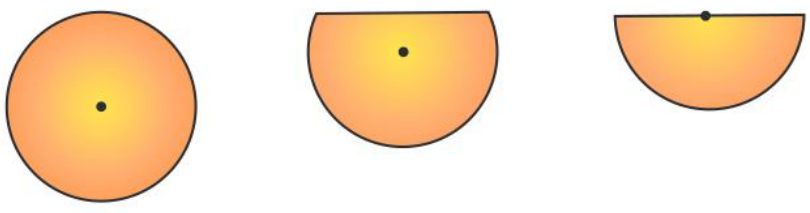


Figure 19.12 The distance from the top of the segment to the segment optical center varies with seg style. Three different seg styles, all set for the same vertical height, can have very different locations for their segment optical centers.

is entering an area of the segment with base-down prismatic effect. If the segment were to be in the upper part of the lens, as with occupational double-D segments, when the eye looks upward, it crosses into an inverted upper segment. The prismatic effect caused by the place on the segment where the eye enters it will be base up. In this specialized case, the jump will be in a downward direction.)

Example 19.6

How much jump does a flat-top segment such as the one shown in Figure 19.12, *B*, have? The segment dimensions are as follows:

$$\begin{aligned}\text{Seg width} &= 25\,\text{mm}\\ \text{Seg depth} &= 17.5\,\text{mm}\\ \text{Add}: &+1.50\text{D}\end{aligned}$$

Solution

A flat-top style seg is essentially a small round lens with the top cut off. Therefore, to find the distance from the seg line to the seg OC, subtract one half of the seg width from the seg depth.

$$17.5\,\text{mm} - 12.5\,\text{mm} = 5\,\text{mm}$$

Image jump is determined by finding the prismatic effect of the segment at the point on the upper seg line. In this case, since the distance from the seg OC is 5 mm, we use

$$\Delta = cF = (0.5)(1.50) = 0.75\,\text{Base down}$$

giving an upward image jump of 0.75Δ.

ACCOMMODATION THROUGH SPECTACLE LENSES

There are several mysteries when it comes to comparing plus and minus lens wearers. Here are a few of them:

- Why do hyperopic spectacle lens wearers seem to need bifocal or progressive lenses before myopic lens wearers?
- Why do middle-aged myopes sometimes have trouble with reading when switching into contact lenses but middle-aged hyperopes do not? In fact, the hyperopes going into contact lenses seem to postpone the need for a reading correction.
- Why do some previous spectacle lens–wearing myopes have trouble with reading after undergoing refractive surgery?

All of these questions relate to the effect of spectacle lenses on accommodative demand. In this section, we will be showing how accommodative demand is affected by spectacle lenses compared with contact lenses and no lenses at all.

Who Needs Bifocal or Progressive Lenses First, the Hyperope or the Myope?

The amount of accommodation required for an individual to see clearly at near is determined by three things:

1. The near-viewing distance
2. The power of the distance spectacle lens prescription being worn
3. The distance from the lens to the principal planes of the eye

The primary and secondary principal planes of the eye are those planes perpendicular to the optic axis at which refraction of incident and emergent light is considered to take place. The distance from the spectacle lenses to the principal planes of the eye is approximately the vertex distance plus 1.5 mm. (According to Gullstrand's schematic eye, the two principal planes of the eye are 1.47 mm and 1.75 mm behind the cornea.)

To tell who will need a bifocal lens first, consider the situation of the emmetrope who needs no distance corrective lenses. Suppose this emmetrope is wearing an empty frame at a 12.5-mm vertex distance. No accommodation is required for viewing objects in the distance. This is because light entering the eye from infinity is parallel, having a zero vergence. At the normal reading or near working distance, the emmetrope looks at an object that is 40 cm from the spectacle plane. This means that light first travels 40 cm from the near object to the frame, then 12.5 mm from the spectacle plane to the cornea, and, finally, 1.5 mm from the cornea to the principal planes of the eye. In other words, the near object is −40.14 cm or −0.4014 m away from the principal planes of the eye. The amount of accommodation required to focus the near object through the "glasses" is the difference between the vergence of light coming from a distant object and the vergence of light coming from a near object. That is to say,

$$\text{Ocular accommodation} = L_d - L_n$$

where L_d is the vergence of light reaching the principal planes of the eye from a distant object (infinity). L_n is the vergence of light reaching the principal planes of the eye from some specific near point or near object. (This point might not be the viewing location where all accommodation is being used.)

For the emmetrope, the amount of ocular accommodation required is

$$\begin{aligned}\text{Ocular accommodation} &= L_d - L_n\\ &= \frac{1}{\infty} - \frac{1}{-0.4014}\\ &= 0.00 - (-2.49)\\ &= 2.49\end{aligned}$$

So, the amount of ocular accommodation required to view reading material at this customary working distance is 2.49 D.

The next question is, does this required ocular accommodation of 2.49 D remain the same for a hyperopic spectacle lens wearer? To find out, solve Example 19.7.

Example 19.7

How much must a wearer of +7.00 D single-vision spectacle lenses have to accommodate to clearly see an object that is 40 cm away from the spectacle plane? (Assume a 12.5-mm vertex distance.)

Solution

Remember, ocular accommodation is the difference between distance and near vergence at the principal planes of the eye. Finding the vergence of light at the principal planes of the eye after being refracted through a lens is basically the same as working a compensated power problem (see Chapter 14). The compensated power is the same as the vergence light would have at the new reference position. We want to compare the vergences of light for distance and near. Written as a formula, compensated power was shown as

$$F_C = \frac{1}{\frac{1}{F_v'} - d}$$

where F_C was the compensated power at the new reference plane.

Now we will use L_d instead of F_C, making the formula

$$L_d = \frac{1}{\frac{1}{F_v'} - d}$$

where
L_d is the vergence of light at the corneal plane from infinity,
F_v' is the back vertex power of the lens, and
d is the distance in meters from the reference position of the lens to the new reference position.

This time, however, instead of using vertex distance for d as was used in working compensated power problems in Chapter 14, use principal plane distance (i.e., vertex distance plus 1.5 mm) (Figure 19.13). This will make L_d equal to the vergence of light at the principal planes of the eye. Therefore, for the +7.00 D hyperope,

$$L_d = \frac{1}{\frac{1}{+7.00} - 0.014}$$
$$= +7.76\text{D}$$

For a near object at 40 cm, the vergence of light striking the lens is 1/−0.40, which is the same as −2.50 D (Figure 19.14). This vergence must be added to the power of the lens to find the vergence of light leaving the lens. The vergence of light leaving the lens is

$$\text{Exiting vergence} = \left(\frac{1}{-040}\right) + F_v'$$
$$= -2.50 + 7.00$$
$$= +4.50\text{D}$$

This means that the vergence of light for the near object at the principal planes of the eye would be

$$L_n = \frac{1}{\left(\frac{1}{\frac{1}{-0.40} + F_v'}\right) - d}$$
$$= \frac{1}{\left(\frac{1}{\frac{1}{-2.50} + F_v'}\right) - d}$$
$$= \frac{1}{\left(\frac{1}{\frac{1}{-2.50 + 7.00}}\right) - 0.014}$$
$$= \frac{1}{\left(\frac{1}{4.5} - 0.014\right)}$$
$$= \frac{1}{0.208}$$
$$= +4.80\text{D}$$

Then, for a +7.00 D hyperope, the amount of accommodation required to clearly see an object at 40 cm would be +7.76 −4.80 = 2.96 D. This amounts to approximately ½ D more accommodation required than for an emmetrope.

If the same calculations were done for a −7.00 D myope, the ocular accommodation would be found to be only +2.00 D. This is less than would normally be expected. In other words, a +7.00 D hyperope wearing single-vision lenses must accommodate almost a full diopter more than a −7.00 D myope to clearly see an object at 40 cm. *This means that a spectacle-wearing hyperope will require a near addition before a myope will.*

(Note: The previous formula method is not the only way to work ocular accommodation problems. It is possible to work such problems using vergences. Formulas are arguably easier to do, but vergences have the advantage of clarifying what is going on conceptually.)

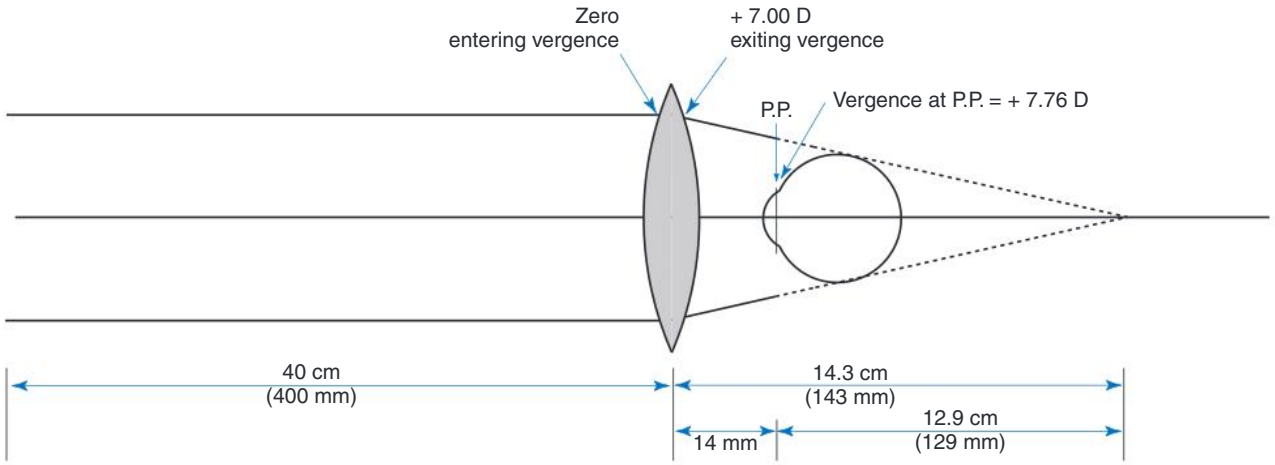


Figure 19.13 When light travels through a spectacle lens, the vergence of light reaching the eye is different from the vergence of light that left the back surface of the lens. *P.P.,* Principal plane.

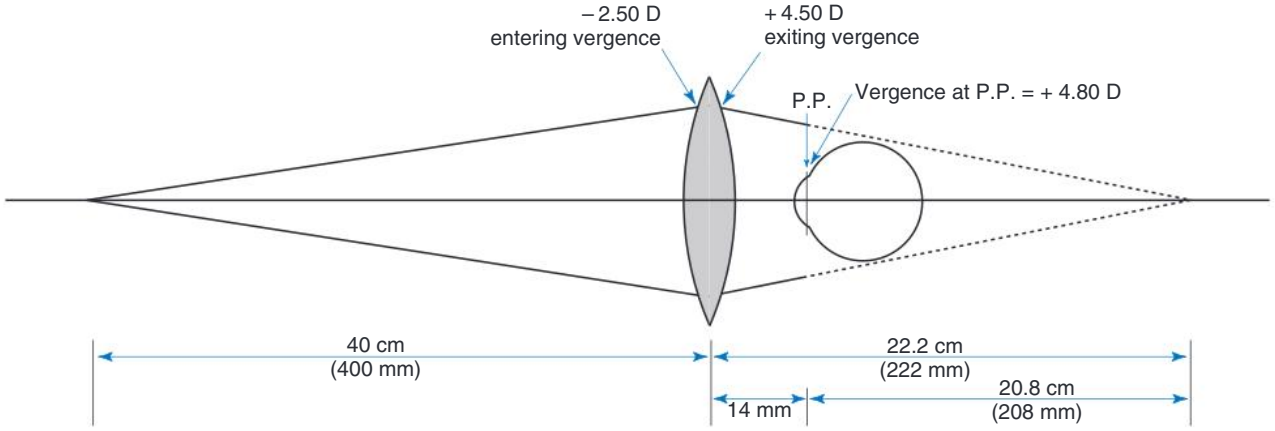


Figure 19.14 The amount of ocular accommodation required is the difference between distance and near vergence at the eye. In this case, the amount of ocular accommodation required is +7.76 − 4.80 = + 2.96. This is more than the approximately +2.50 D of accommodation expected for an object viewed at 40 cm. *P.P.,* Principal plane.

How Contact Lenses Affect Required Accommodation

In spite of differences in required accommodation for spectacle lens–wearing myopes and hyperopes, a contact lens–wearing hyperope will not need bifocal lenses any sooner than a contact lens–wearing myope because contact lenses rest directly on the eye. Contact lenses will return high plus and high minus lens wearers to an optical situation that closely resembles the emmetrope, thus equalizing accommodative differences (Table 19.3).

What Happens as Add Power Increases

Interestingly, once a spectacle-lens wearer goes into bifocal lenses, as the add power increases, differences in the amount of accommodation required for hyperopes and myopes decrease. When full presbyopia is reached, the +7.00 D hyperope does not need the nearly +3.00 D add that might be expected. This is because light from 40 cm diverges to −2.50 D at the spectacle plane, but the +2.50 add in the spectacle plane changes the diverging light back to parallel. Thus, light rays leaving the add enter the distance lens parallel and are able to be focused on the retina just as if they were coming from a distant object.

TABLE 19.3 Examples of Differences in Required Accommodation

Spectacle Lens Correction	Accommodation Required When Wearing Spectacle Lenses	Accommodation Required When Wearing Contact Lenses (or After the Eye Has Been Corrected by Refractive Surgery)
−7.00 D Myope	2.00 D	2.49 D
0.00 D Emmetrope	2.49 D	2.49 D
+7.00 D Hyperope	2.96 D	2.49 D

These examples are based on a near object being viewed at a distance of 40 cm in front of the spectacle plane when the spectacle plane is 14 mm in front of the principal planes of the eye. Thus, the near object is really 40.14 cm in front of the eyes' principal planes.

Determining Occupational Add Powers for New Working Distances

When someone needs a second pair of glasses for a specific occupational need, the working distance may not be the same as it is for normal wear. Usually, the near prescription has been determined for a 40-cm working distance. At the new working distance, the wearer needs to be accommodating the same amount as they did for their regular working distance. This ensures that the near prescription will be neither too strong nor too weak. Therefore, there must be a change in the add power. The prescriber can retest at this new working distance and find the correct add power. If the prescription is already written and is being filled at a secondary location, it is possible to calculate a new add power using the optical principles previously described. However, it is more advisable to request that the original prescriber determine the needed add power.

Why Some Nonpresbyopes Need a Different Cylinder Correction for Near

Occasionally, a nonpresbyope with an occupation requiring intense near work complains of eye fatigue with near viewing. In spite of all efforts on the part of the examiner to uncover the source of the problem by checking and rechecking the refraction, the solution remains elusive. When the prescription contains a high cylinder power, there may be an optical answer that is not immediately obvious.

As shown previously, the power of a spectacle lens will affect the amount of accommodation required for near viewing. A spectacle lens containing a large cylinder component has a considerable difference in refractive power between its two major meridians. This means that a single-vision lens wearer may require a different amount of accommodation for one meridian of the lens than for the other when comparing the effectiveness of that lens at distance and near. If the distance sphere power is also large, this effect can be even more significant. The net effect of these differences results in a new astigmatism at near that is different from the value found for distance vision. This new amount of astigmatism is not fully corrected at the near reading distance and may be the root of the problem.

The initial response may be to calculate a new cylinder correction for near. Yet rather than try to calculate a new cylinder correction to remedy the near problem, the best solution is to test for cylinder power and axis for near vision. Retesting with a near target during refraction is better than recalculating because there can often be a slight amount of

cyclorotation of the eyes upon convergence. (Cyclorotation is a clockwise or counterclockwise turning of the eye around an imaginary axis corresponding to the line of sight.) Cyclorotation will change the cylinder axis. Therefore, in cases like this, it is best to test for both cylinder power and axis at near.

If there is a difference between distance cylinder values and near cylinder values, a second, single-vision pair of glasses is needed for near work. Fortunately, this problem also resolves as presbyopia advances.

CREATING HORIZONTAL PRISM AT NEAR ONLY

Occasionally, a prescription will call for horizontal prism but only for near viewing. Why might someone need prism only at near working distances? The situation does not happen often, but there are times when it can be an advantage to create base-in or base-out horizontal prism for near only. It could also happen that there is already horizontal prism in the distance portion of the lens, but a different amount is needed in the near-viewing area. Although beyond the scope of this textbook, examples of those who might benefit from different amounts of horizontal prism at near include those with high accommodative convergence to accommodation (AC/A) ratios, intermittent near tropias, and noncomitant strabismus.

If horizontal prism is ordered for near only (or a different amount at near than at distance), then there are several ways to address the issue:

1. *Use two pairs of glasses*—With two pair of glasses, the distance prescription is given without prism. A second pair for near viewing is given and includes both horizontal prism and the near add power.
2. *Use Fresnel press-on prism for near only*—Although Fresnel prism fulfills the intent of the prescription, it does not offer a permanent solution.
3. *Use larger-segment flat-top lenses and decenter the segments*—Base-in or base-out prism is created by having the laboratory move the segments in or out relative to their traditional near PD location.
4. *Use a split lens*—Each lens in the pair is formed from two separate lenses as described for a Franklin-style bifocal lens. The upper half of a distance-powered lens is cemented to the lower half of a near-point powered lens containing the desired prism. This is described in greater detail at the end of this chapter in the section titled *A Split Lens for Prism at Near.*
5. *Use a cement seg construction*—Some laboratories are able to use a single-vision lens for the distance prescription and glue a specially constructed segment lens onto the single-vision lens. The segment must have a back curve equal to the front curve of the distance lens. The segment can be made with prism only or with prism and an add power.
6. *Use a Neurolens*—A Neurolens is a proprietary lens design that is available in progressive, single-vision, and computer lenses. It is prescribed using a measurement device designed specifically for that purpose. The lens uses "contoured prism" that gradually increases in amount between distance and near-viewing areas to correct for gradually changing convergence insufficiency.

Large-Segment Flat Tops: Horizontal Prism at Near Using Segment Decentration

The least expensive method for correcting horizontal prism at near with a multifocal lens is to use larger flat-top segments. These segments are decentered more or less than they normally would be for the near PD (Figure 19.15). The amount of segment decentration required depends on the power of the near addition. There are some restrictions:

- If too much decentration is required, it will not be possible to move the segment far enough. The lens size will not allow it.

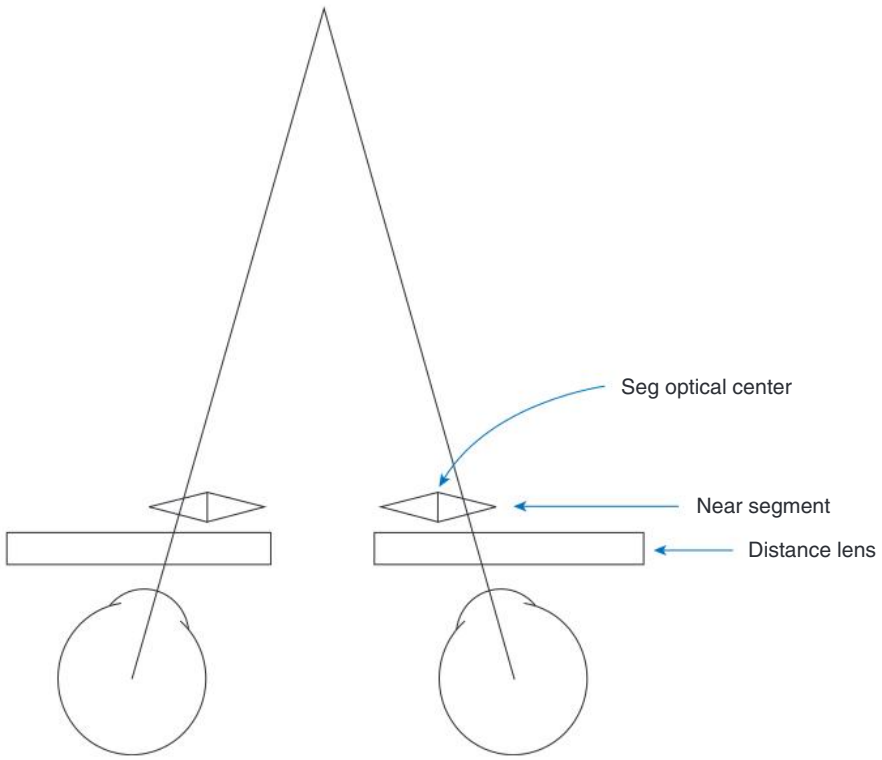


Figure 19.15 Bifocal segments are really small plus lenses. This means that if the segment optical centers are moved nasalward, they will cause a base-in prismatic effect. This prismatic effect occurs only in the near position.

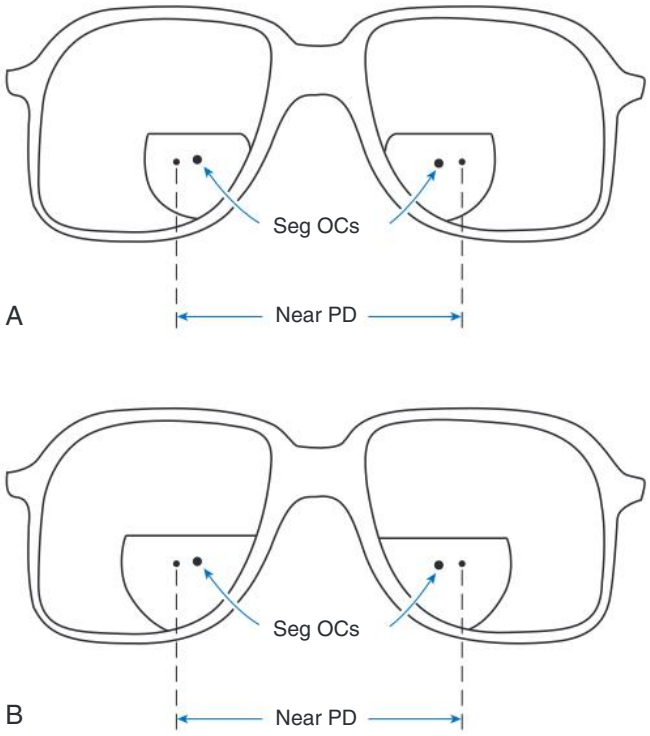


Figure 19.16 The eyes do not remain at the near interpupillary points when close work is done. They scan back and forth. The production of lateral prism at near through segment decentration requires that attention be given to seg width. In **A,** there will not be enough viewing area in the outer (temporal) part of the seg to permit normal eye movement when reading. In **B,** a larger segment size is chosen. This solves the problem, and there is now enough space in the segment to permit comfortable reading. *OCs,* Optical centers; *PD,* interpupillary distance.

- If the segment is too small, the edge of the segment will be too close to the line of sight, and there will not be enough reading area.

Thus, the practitioner must know how far the segments must be decentered and what the minimum size of those segments must be so that there is still enough segment reading area remaining (Figure 19.16).

Steps in Finding Segment Decentration and Size for Prism at Near

The following steps outline how the amount of segment decentration is determined and reveal how large the segment must be so that sufficient segment area remains for reading. (These steps are summarized in Box 19.1.)

1. Find the customary seg inset.

$$\text{Seg inset} = \frac{\text{Distance PD} - \text{Near PD}}{2}$$

2. Find the additional seg inset needed to produce the prism prescribed for near using a transposed form of Prentice's rule.

Now for some examples on how this is done.

Example 19.8

A prescription reads

+2.00 − 1.00 × 180	1.25Δ base in at near only
+2.00 − 1.00 × 180	1.25Δ base in at near only
Add: +2.25	
PD = 64/60	

BOX 19.1 Finding Seg Decentration and Size for Prescribed Prism at Near Only

1. Find the customary seg inset.

$$\text{Seg inset} = \frac{\text{Distance PD} - \text{Near PD}}{2}$$

2. Find the additional seg inset needed to produce the prism prescribed.

$$c_a = \frac{\text{Near prism}}{F_a}$$

where c_a = additional set inset and F_a = the add power.

3. Determine if the additional seg inset is inward or outward. Because the segment is really a small plus lens, if the prescribed near prism is base in, the additional seg inset will be inward. If the prescribed near prism is base out, the additional seg inset is outward.
4. Find the net seg inset.

$$\text{Net seg inset} = \text{Seg inset} + \text{Additional seg inset}$$

5. Find the minimum segment size needed to give the wearer enough area to read.

$$\text{Seg size} = 2(10 + \text{Additional seg inset})$$

Could this amount of prism correction be achieved using decentered flat-top segments? If so, how large should the segs be so that they give at least a 10-mm distance from the reading center to the edge of the segment? The reading center is at the location of the near interpupillary distance (PD).

Solution

To find the answers to these questions, proceed through the steps outlined in the preceding section.

1. For this prescription, the customary seg inset is

$$\text{Seg inset} = \frac{\text{Distance PD} - \text{Near PD}}{2}$$
$$= \frac{64 - 60}{2}$$
$$= 2\,\text{mm}$$

2. Find the additional amount of decentration needed beyond what would normally be required for the near PD. To do this, use Prentice's formula in this format

$$c_a = \frac{\text{Near prism}}{F_a}$$

In this case,

$$c_a = \frac{1.25\Delta}{2.25\,\text{D}}$$
$$= 0.55\,\text{cm}$$
$$= 5.5\,\text{mm}$$

3. Because the horizontal prism at near is base in, the additional seg inset is also inward.
4. Therefore, the net seg inset is

$$\text{Net seg inset} = \text{Seg inset} + \text{Additional seg inset}$$
$$= 2 + 5.5$$
$$= 7.5\,\text{mm}$$

5. The minimum segment size needed will be

$$\text{Seg size} = 2(10 + \text{Additional seg inset})$$

Additional seg inset was the c_a value found in step 2. So, in this case,

$$\begin{aligned}\text{Seg size} &= 2(10 + 5.5)\\ &= 2(15.5)\\ &= 31\,\text{mm}\end{aligned}$$

Since flat-top segs do not come in 31-mm sizes, the next largest segment is chosen. That size is a 35-mm segment.

To summarize, use flat-top 35-mm segments, and decenter these segments 7.5 mm inward for each eye.

A Note About Minimum Segment Size

The equation for finding minimum segment size is

$$\text{Seg size} = 2(10 + \text{Additional seg inset})$$

So, from where does the number 10 originate? The number 10 is the distance between two points in the near segment. The first point is the location in the segment where the eye views near reading material. Since the segment is decentered, this point is not the segment OC. Instead, it is the point where prescribed prism for near is correct. The second point is the edge of the segment that is closest to the first point. This 10- mm distance between the two points means that the reading area for this half of the segment is like reading through a 20- mm wide bifocal segment. A 20- mm wide segment is the smallest segment size that was successfully used; that is, a 20- mm round segment. Knowing this, one can see that this segment size really is a minimum size. *Therefore, using a larger segment than the minimum calculated value would be advantageous.*

Example 19.9

Suppose we want to know the position of the seg in the previous example in terms of near interpupillary distance (PD). What would the near PD be for this prescription? (In this case the near PD is really the horizontal segment center separation and does not at all correspond to the wearer's PD at near.)

Solution

If net seg inset is 7.5 mm per lens, then the distance between the near segs will be closer together than the distance PD by an amount equal to twice the net seg inset. This means that the distance between the near segs is (2) × (7.5) or 15 mm less than the distance PD. The distance between seg centers for this prescription is

$$\begin{aligned}\text{"Near PD"} &= \text{Distance PD} - 2(\text{Net seg inset})\\ &= 64 - 2(7.5)\\ &= 64 - 15\\ &= 49\,\text{mm}\end{aligned}$$

The amount of prism at near will be achieved when the far PD equals 64 mm and the distance between the near PD seg centers is 49 mm. Written on an order form, this would read 64/49. (Before writing something like this on an order form, there should be some explanation. Otherwise, such numbers would certainly be taken as an error.)

Additional Comments on Prism at Near

If a frame with a large eye size is chosen, the decentered lens blank may not be large enough. When it appears that blank size may become an issue, it is advisable to check for minimum blank size (see Chapter 5).

If the segment requires a significant amount of outward decentration to achieve base-out prism at near, a blank size problem can often be solved by having the laboratory swap lens blanks—left for right and right for left. In other words, use a left lens blank to grind the right lens and a right lens blank to grind the left lens.

Ordering Horizontal Prism at Near

As stated previously, the least expensive option for producing prism at near only is that of decentered near segments. By figuring the decentration needed, making certain the lenses will cut out and, when needed, specifying the prism as "distance PD/near PD" as in Example 19.9, the practitioner should be able to determine ahead of time if decentering segments to create near prism will work before placing an impossible order. The method just outlined makes this feasible. That said, a knowledgeable laboratory can be of great help in determining the feasibility of using decentered segs to produce horizontal prism at near.

A Split Lens for Prism at Near

When the amount of prism prescribed for near is different from the distance prism correction, it is possible to use a split lens. Each of the lenses in the pair begins as two lenses—one nonprism distance lens and another lens for near that includes the prescribed prism along with the add power. The prism can be in any base direction since there are really two lenses. The lenses are both cut in half. The upper half of the distance-powered lens and the lower half of the near-powered lens are glued together. As noted previously, there can be prism in both distance and near areas—each with a separate prism amount.

The laboratory does this by making both lenses with the same base curve. The laboratory will try to match the center thicknesses of the two lenses. Once the two lenses are made, the lens to be used as the upper half is spotted, and a "seg line" is marked on this distance lens so that the distance OC will be 3 or 4 above the seg line. The lens will be cut along the seg line. Another seg line is marked on the near lens. For this lens, the part below the seg line will be used. The lenses are cut, and the cut edges are smoothed. Then the two halves are glued together and allowed to dry. Now the newly created lens is spotted, blocked, and edged for the frame.

The person receiving a split lens should be told that this lens is not as impact-resistant as other lenses and should be asked to sign a disclaimer for impact resistance. Although it may be possible to make a cement seg lens from a single-vision lens that could be more impact resistant, such a lens may not be as suitable.

Applicable for Any Horizontal Prism at Near

It should be noted that none of the methods for correcting with horizontal prism at near are limited to lenses without prism in the distance prescription. All methods can be used when there is prescribed horizontal prism in the distance portion and a different amount of prism prescribed for near viewing.

REFERENCE

1. Three Rivers Optical "O" Seg, www.3riversoptical.com/tr-o-seg/. Accessed 11/22/2021.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

Segmented Multifocal Lenses

1. Which of the following is correct?
   a. (Distance power) − (Near power) = (Near addition)
   b. (Near power) − (Distance power) = (Near addition)
   c. (Near addition) = (Distance power) − (Near power)
   d. None of the above is correct.
2. Which of the following statements is correct?
   a. Seg height is always equal to seg depth.
   b. Seg depth is always greater than or equal to seg height.
   c. Seg height is always greater than or equal to seg depth.
   d. Seg height is always greater than seg depth.
   e. None of the above is correct.
3. If a right lens has an outset of 1 mm and a seg inset of 2.5 mm, what is the total inset?
   a. 1.0 mm
   b. 1.5 mm
   c. 2.5 mm
   d. 3.5 mm
   e. None of the above is correct.
4. The lensmeter reads a trifocal lens as follows:
   −1.00 −1.00 × 180 in the distance portion
   +0.50 −1.00 × 180 in the intermediate portion
   +1.50 −1.00 × 180 in the near portion
   What is the near add?
   a. +1.50 D
   b. +1.75 D
   c. +2.00 D
   d. +2.25 D
   e. +2.50 D
5. In Question 4, what is the percentage of intermediate seg power?
   a. 40%
   b. 50%
   c. 60%
   d. 70%
   e. None of the above is correct.
6. If you could not see a segmented multifocal lens and were only able to feel the surfaces, which of the following multifocal lenses could not be distinguished from a single-vision lens?
   a. A fused glass multifocal lens
   b. A one-piece construction multifocal lens
   c. A cement segment multifocal lens
   d. All could be distinguished from a single-vision lens.
   e. None could be distinguished from a single-vision lens.
7. An Executive lens is an example of which type of construction?
   a. fused
   b. one piece
   c. cement segment
8. Which of the following multifocal lens construction methods are used only with glass?
   a. fused
   b. one piece
   c. cement segment
9. True or false? One-piece multifocal lens construction is used only with plastic lenses, not with glass.
   a. True
   b. False
10. A lens has the following dimensions:
    Shape: rectangular
    Depth of lens (the B dimension) = 36 mm
    Width of the lens (the A dimension) = 50 mm
    Rx : O.D. + 2.50 − 1.50 × 090
    O.S. + 2.50 − 1.50 × 090
    Add: +1.75 O.U.
    Seg dimensions: seg width = 28 mm
    seg depth = 19 mm
    seg height = 15 mm
    seg inset = 2 mm
    What is the seg drop?
    a. 6 mm
    b. 5 mm
    c. 4 mm
    d. 3 mm
    e. None of the above is correct.

Image Jump

11. What is the "jump" in a 22-mm round bifocal lens with a distance prescription of +2.00 D sphere, seg 3 mm below distance center, and power of add +2.00 D?
    a. 0.60Δ
    b. 2.20Δ
    c. 3.00Δ
    d. There is no jump with this lens.
    e. None of the above is correct.
12. Calculate the "jump" for the following bifocal lens:
    +3.00 − 1.00 × 080; add of +2.50 D
    Seg top is 3 mm below distance optical center (OC). Seg style is a straight-top 25 with the segment OC 5 mm below the dividing line.
    a. 1.25Δ
    b. 1.75Δ
    c. 2.25Δ
    d. 2.75Δ
    e. None of the above is correct.
13. Give the image jump for the following prescription:
    O.D. + 3.00 − 1.00 × 180
    O.S. + 3.50 − 1.25 × 180
    Add : 2.25 D
    Frame B dimension = 42 mm
    Seg height = 15 mm
    Seg style is an Executive.
    a. 1.25Δ
    b. 1.35Δ
    c. 3.37Δ
    d. 0.00Δ
    e. None of the above is correct.

Ordering for Reading and Intermediate Distances

14. A prescription reads as follows:
−0.50 −0.25 × 180
−0.50 −0.25 × 180
Add: +2.00
The wearer wants a pair of glasses for distance and a pair for reading. What powers would be ordered for the reading glasses?
a. +2.00 D sphere
+2.00 D sphere
b. +2.00 −0.25 × 180
+2.00 −0.25 × 180
c. +2.50 −0.25 × 180
+2.50 −0.25 × 180
d. +1.50 D sphere
+1.50 D sphere
e. +1.50 −0.25 × 180
+1.50 −0.25 × 180

15. A trifocal lens wearer has the following prescription:
O.D. − 1.25 − 0.50 × 005
O.S. − 1.75 − 0.25 × 175
Add: +2.50 D
Trifocal lens with 50% intermediate portion
The wearer finds the intermediate power exactly correct for the desktop monitor at which she works, and the near power is just right for paperwork. She never uses the distance portion. What lens prescription would serve the purpose?
a. pl −0.50 × 005
−0.50 −0.25 × 175
Bifocal add: +2.50
b. −0.62 −0.50 × 005
−1.12 −0.25 × 175
Bifocal add: +1.75
c. −2.25 −0.50 × 005
−2.75 −0.25 × 175
Bifocal add: +1.25
d. pl −0.50 × 005
−0.50 −0.25 × 175
Bifocal add: +1.25
e. None of the above is correct.

Accommodation and Spectacle Lenses

16. A 41-year-old individual is just beginning to have some problems working at near distances for prolonged periods of time. Interest is expressed in the possibility of changing from spectacles to contact lenses. The distance prescription is:
R: + 6.75 − 0.75 × 180
L: + 6.75 − 0.75 × 180
Which of the following is true?
a. This individual will have even more difficulty with fatigue at near in contact lenses than in spectacle lenses.
b. This individual will have less difficulty with fatigue at near in contact lenses than in spectacle lenses.
c. This individual will not experience much difference in contact lenses versus spectacle lenses regarding fatigue at near.

17. Of the following spectacle lens prescriptions, which spectacle lens wearer may have more difficulty with eye fatigue at near than the others?
a. −2.00 −1.00 × 180
−2.00 −1.00 × 180
b. −3.00 −2.50 × 180
−3.00 −2.50 × 180
c. −5.50 −3.50 × 180
−5.50 −3.50 × 180
d. −6.00 −3.75 × 180
−6.00 −3.75 × 180
Add: +2.25

18. A 50-year-old −6.00 D myope with a +1.00 add power decides to have refractive surgery. What would you expect after refractive surgery assuming that, after surgery, both eyes have a zero distance refractive error?
a. This person will probably still need a +1.00 D add, even after refractive surgery.
b. This person will need a slightly lower add power than he or she had before surgery.
c. It is doubtful that this person will even need an add following refractive surgery regardless of the type of intraocular lens implant used by the surgeon.
d. This person will need an add power greater than +1.00 D following refractive surgery.

Horizontal Prism at Near Only

19. A prescription calls for 0.75Δ of base-in prism per lens in the segment only. To produce this amount by seg decentration, how much additional seg inset is required beyond the amount that has been determined by near interpupillary distance (PD) measurement or calculation? (The power of the add in question is +2.00 D.)
a. 1.5 mm additional seg inset per lens
b. 2.7 mm additional seg inset per lens
c. 3.8 mm additional seg inset per lens
d. 1.5 mm counterbalancing seg outset per lens
e. none of the above

20. A prescription reads:
+0.50 −0.75 × 005 1.50Δ base in at near only
+0.50 −0.75 × 175 1.50Δ base in at near only
Add: +2.00
PD = 66/62
How much net seg inset is required to achieve the correct amount of prism at near only using flat-top segments?
a. 2.75 mm
b. 7.00 mm
c. 9.5 mm
d. 11.5 mm

21. For the same prescription as in the previous problem:
+0.50 −0.75 × 005 1.50Δ base in at near only
+0.50 −0.75 × 175 1.50Δ base in at near only
Add: +2.00
PD = 66/62
At a minimum, how large should the segs be so that they give at least a 10-mm distance from the reading center at the near PD to the edge of the segment?
a. 25 mm
b. 28 mm
c. 35 mm
d. 40 mm

22. A prescription has distance powers of pl −1.00 × 180 with a +2.00 add power. The prescription also calls for 1.5Δ of prism base in per eye at near only. If you were to use decentered flat-top 35-mm segments to create prism at near, which direction would you decenter the segments?
a. inward
b. outward

23. A prescription reads:
+1.00 −0.50 × 180 2.00 base in near only
+1.00 −0.50 × 180 2.00 base in near only
Add: +2.25
PD = 65/62.
The prism at near is to be created by decentering the segs horizontally. To the nearest millimeter, what should the distance between segment OCs be for the wearer's glasses if measured with a PD ruler in the usual manner?
a. 40 mm
b. 44 mm
c. 47 mm
d. 80 mm

24. To the nearest millimeter, what would the minimum theoretical lens segment size be to permit near work for the prescription in the previous question? (The answer does not have to correspond to an available lens multifocal segment.)
a. 28 mm
b. 31 mm
c. 35 mm
d. 38 mm
e. 45 mm

25. A prescription reads:
−2.00 −0.50 × 090 2.50 base out near only
−2.00 −0.50 × 090 2.50 base out near only
Add: +2.00
PD = 64/61.
The prism at near is to be created by decentering the segs horizontally. To the nearest millimeter, what would the net seg inset or outset need to be for each segment?
a. 6.5 mm outset
b. 8 mm outset
c. 11 mm outset
d. 12.5 mm outset
e. 14 mm outset

26. For the prescription in the previous question, what is the minimum segment size that would be required for a minimum-sized reading area?
a. 28 mm
b. 35 mm
c. 40 mm
d. 45 mm

27. This is a difficult question. Think it through carefully. A spectacle lens wearer has a distance prescription of − 2.50 D sphere and an add power of +2.50 (in other words, a near power of plano). If the segment is decentered either nasally or temporally, will there be any change in horizontal prismatic effects in the segment viewing area?
a. Yes
b. No

Progressive Addition Lenses

SECTION 1: MEASUREMENT AND DISPENSING OF PROGRESSIVE LENSES

Progressive addition lenses (PALs) are made with the help of specially designed surface curves. These changing surface curves cause the lens to gradually increase in plus power, beginning in the distance portion and ending in the near portion. These variable-powered PALs should, according to design, permit clear vision at any given viewing distance merely by positioning the head and eyes.

PROGRESSIVE LENS CONSTRUCTION

Like a segmented multifocal lens, a *PAL* has certain distinct areas to the lens. But those areas in a progressive lens are not visible. If we were able to see them, they would look like the lens in Figure 20.1.

The upper portion of the lens is basically the distance portion. The near portion of the lens, where the full near addition power is found, is down and inward. In between the distance and near portions is a *progressive corridor* where the power of the lens is gradually changing.

SELECTING THE FRAME

When choosing a frame for someone wearing a progressive addition lens there must be enough room for the progressive zone and near portion. Because these areas are not visible like a bifocal segment is, they may be unintentionally cut off during lens edging. This was a problem when progressive lenses were first introduced. At that particular time, many frames had narrow vertical dimensions. When progressive lenses were dispensed in these frames, much of the near portion was cut off. Since people could not see very well up close, dispensers falsely concluded that the lenses were no good, demonstrating why frame selection is such an important part of fitting progressives. Here are some important points to keep in mind:

1. The frame must have sufficient vertical depth.
2. The frame must have sufficient lens area in the lower nasal portion where the near progressive optics are found. Sometimes, the frame has a large enough "B" dimension, but the shape is cut away nasally. Aviator shapes are an example of this type of frame.
3. The frame should have a short vertex distance. The closer the frame is to the eyes, the wider the field of view will be for both reading and distance vision.
4. The frame must be able to be adjusted for pantoscopic angle when facial structure will allow. A 10- to 12-degree angle is recommended. The intermediate and near fields of view are effectively wider when the progressive and near zones are closer to the eyes.
5. The frame must have sufficient face form. This also allows a wider viewing area through the progressive corridor.

Frame selection criteria for progressive addition lenses are discussed in greater detail in Chapter 4. The reader is encouraged to review this section, noting especially Figure 4.4.

CHOOSING THE RIGHT TYPE OF PROGRESSIVE LENS

Most progressive lenses are made for general purpose wear since the majority of wearers only have one pair of glasses. Although general purpose progressive lenses work for most people, here are some additional considerations:

1. What type of general purpose progressive lens is appropriate? It is possible to choose a certain type of general purpose progressive lens to fit the needs of the wearer. This is discussed in more detail in this chapter under Section 2 General Purpose Progressive Lenses.
2. Does the wearer have a significant amount of cylinder power in the prescription? If so, consider using a higher end progressive lens design that is atoric. Using such a design will reduce the amount of unwanted distortion that will otherwise be present in the periphery of the lens.
3. If the vertical "B" dimension of the frame is small, choose a short corridor progressive lens. A short corridor lens is still used for general purposes but is meant for this type of frame. For more on this topic, see Section 3 Specialty Progressives-Style Lenses.
4. Does this person frequently view computer monitors at an intermediate distance? Do they work in a small office environment where intermediate vision is important? If so, they may need a near variable focus occupational progressive lens. This type of lens is made for closer viewing distances through the top of the lens. It has both a wider intermediate progressive corridor and a wider near-viewing area. An occupational progressive lens should not be used as a person's only pair of glasses, unless this person does not need a distance prescription and would otherwise only be wearing reading glasses. These lenses should be considered for a second pair of glasses. For more on this topic, see Section 3 Specialty Progressive-Style Lenses.

MEASURING FOR AND ORDERING THE PROGRESSIVE LENS

A progressive addition lens has a rather narrow progressive corridor linking the distance and near portions of the lens. It is through this corridor that intermediate vision takes place. Unless the eye tracks down the exact center of this corridor, the lenses do not work very well. Therefore, interpupillary distance (PD) measurements must be taken for each eye individually and an exact vertical height specified for each eye.

To help make sure the progressive corridor is where it should be, the manufacturer uses a *fitting cross*. The fitting cross is usually 4 mm above the start of the progressive corridor and is intended to be placed exactly in front of the wearer's pupil center. The fitting cross is for ease of measurement, since the pupil center is relatively easy to locate.

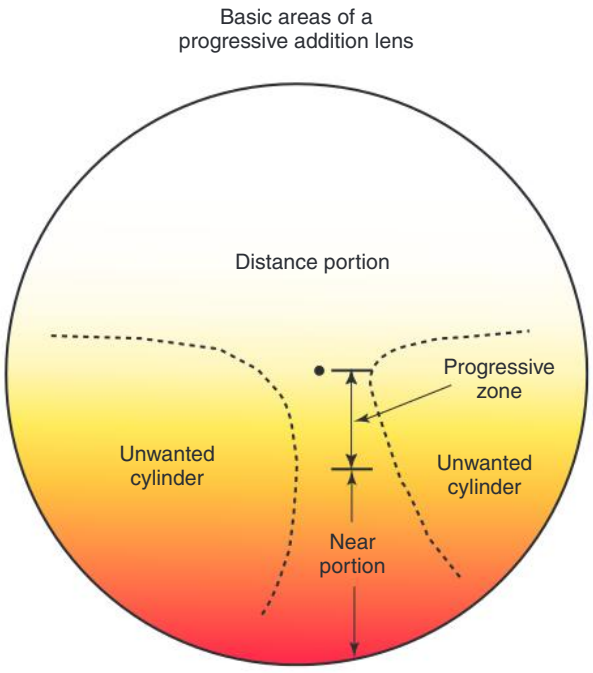


Figure 20.1 The basic construction of a progressive addition lens consists of a distance portion in the upper lens area, a near portion in the lower central area (slightly displaced nasally), and a progressive corridor between the distance and near areas where power gradually increases. On both sides of the progressive and near zones are areas containing a certain amount of unwanted cylinder. Newer progressive addition lens designs are able to control the optics in these peripheral areas better, making them considerably more useful than might be anticipated.

Standard Method for Taking Progressive Lens-Fitting Measurements

The following measurement techniques are applicable to all manufacturers or designs of standard progressive addition lenses, provided the centration chart of the specific manufacturer is used for the lenses being measured. An example of such a chart is shown in Figure 20.2.

1. Measure monocular distance PDs. The most common method is to use a pupillometer. (The use of a pupillometer as well as alternate methods are explained in Chapter 3.)
2. Fit and fully adjust the actual frame to be worn before taking other measurements. Adjustments include pantoscopic tilt, frame height, vertex distance, face form, and nose pad alignment. Make certain the frame is straight on the face. If the temples are not adjusted, hold the frame in place while measuring so that it will not slip down the nose.
3. If the frame does not contain clear plastic demo lenses or the wearer's old lenses, place clear (nonfrosted), transparent tape across the eyewire of the empty frame.
4. The dispenser should position his or her eyes at the wearer's eye level. (Note: If the dispenser's eye is higher or lower than the wearer's, a parallax error will occur, causing the fitting cross height to be too high or too low.[1]) With the wearer looking at the bridge of the fitter's nose, the dispenser draws a horizontal line on the lens or tape. The line should go through the center of the pupil. This is done for both right and left eyes.
5. Place the frame on the manufacturer's centration chart, and move it left or right until the bridge is centered on the diagonally converging central alignment pattern. Then, move the frame up or down until the marked horizontal pupil center lines are on the chart horizontally at the level shown in Figure 20.3. Mark the previously measured PD for each eye as a vertical line that crosses the horizontal one (Figure 20.4).
6. For first one lens and then the other, read the fitting cross heights from the chart. (*Fitting cross height* is the vertical distance from the fitting cross to the level of the inside bevel of the lower eyewire of the frame.) Note: Fitting cross heights are often erroneously referred to as either major reference point (MRP) heights or seg heights. They are really neither even though some lab order forms may require them to be entered as such.
7. Check to see that the fitting cross heights measured are *at least* equal to the manufacturer's minimum fitting height for the selected lens. (Referenced to the lens selected, the *minimum fitting height* is the distance from the fitting cross to the center of the near reference point [NRP].) Fitting a lens at only the minimum fitting height may cut off up to half of the otherwise available viewing area or more. Therefore, for best results, the fitting cross height should exceed the manufacturer's listed minimum height by 2 or 3 mm[2] (see Box 20.1). Minimum progressive addition lens-fitting heights for general purpose progressive lenses will vary, going down to a low of about 18 mm. If there is not enough vertical depth, then either a different frame should be chosen or a special short corridor lens designed for frames with a narrow vertical dimension should be used. Otherwise, there will not be enough reading area.
8. Check the size and shape of the frame using the lens picture on the centration chart. Do this by placing the frame on the lens blank circles of the centration chart so that the cross on the glazed lens overlaps the fitting cross on the picture (Figure 20.5). The circle should completely enclose the frame's lens shape. (Using the centration chart for the type of lens selected will make it easier to visually determine if a minimum fitting height has been achieved.)
9. Record the fitting cross heights and the monocular PDs in the wearer's record and the lab order. Send the frame to the laboratory with the marks still on the lenses.

Replacing One Lens Only (Relative Fitting Heights)

When replacing only one lens in a pair of progressive add lenses, the relative fitting heights for the fitting crosses should be maintained.

Example 20.1

A progressive lens wearer comes into your practice. The frames and lenses they have are new, but the right lens fell out of the frame and is missing. She has her prescription. You are able to identify the exact type of lens from the semivisible marking on the existing lens. You determine that the existing left lens-fitting cross height is 19 mm. You then remeasure both fitting cross heights with the frame in place. The right measures 21 and the left 20. What fitting cross height would you order for the right lens?

Solution

The existing left lens has a measured fitting height of 19 mm. This is 1 mm less than you measured. To maintain relative fitting heights, the right lens that you order should also be ordered 1 mm less than what you measured. Since you measured 21 mm for the right lens, you need to subtract 1 mm from that measurement as well, resulting in a 20 mm fitting cross height. Now both fitting crosses are 1 mm below pupil center, duplicating the previous fitting height situation. If you had ignored the left lens-fitting cross height of 19 mm and ordered a 21 mm fitting height for the right lens, you may have created a problem.

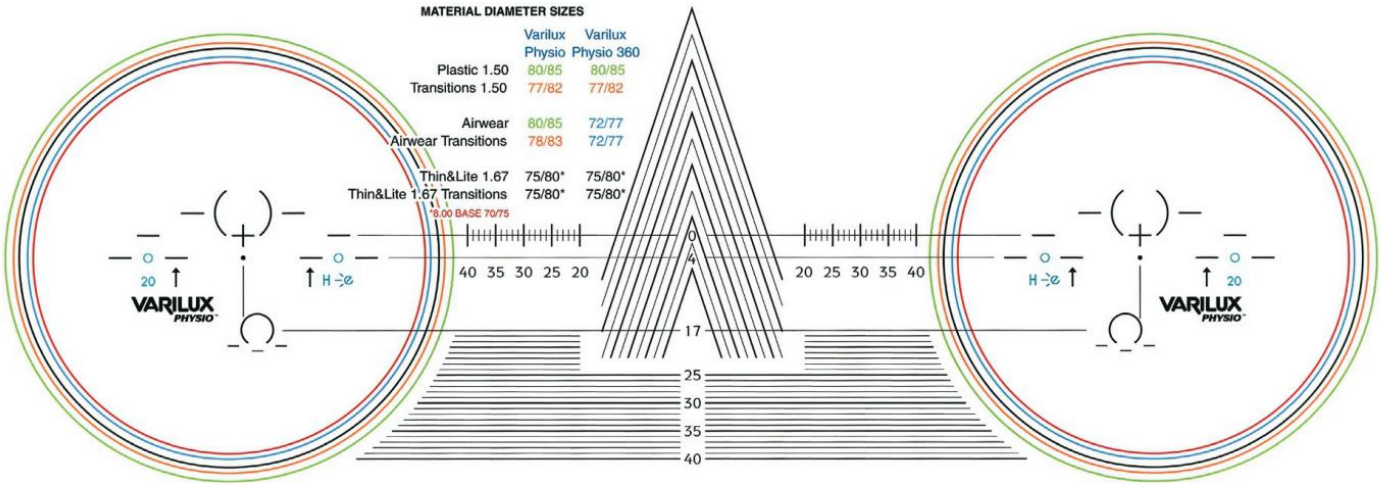


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Figure 20.2 The manufacturer's centration chart allows for easy reading of the fitting cross height. When monocular interpupillary distances have not been previously measured with a pupillometer but were marked on the lenses, their distances may be easily determined with the help of the horizontal scale on the chart. (The circles are for determining minimum blank size.) (Courtesy of Essilor of America, Dallas, TX).

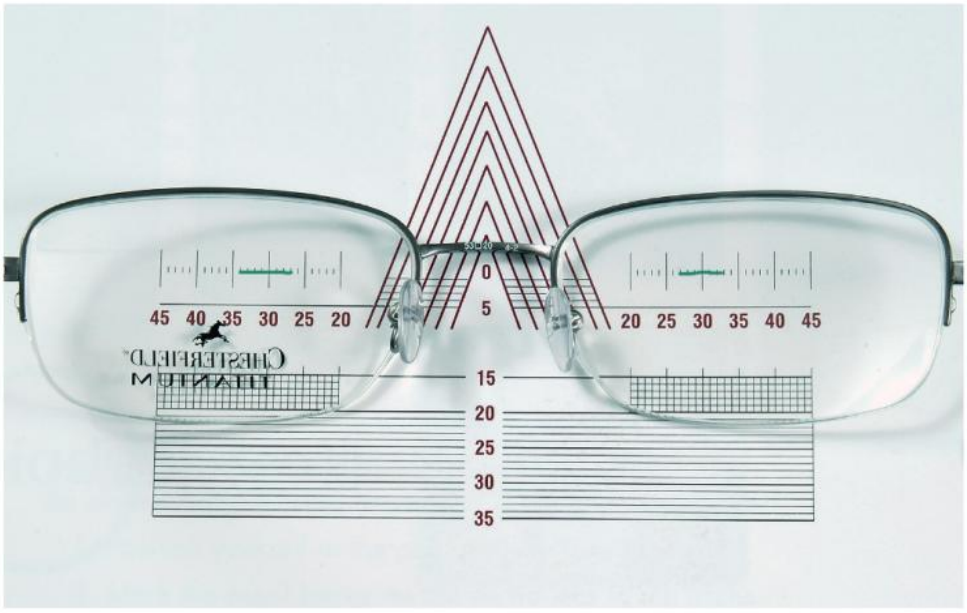

Figure 20.3 For this pair of glasses, the fitting cross heights are marked. The frame bridge is centered on the arrowhead lines. The fitting cross lines are positioned on the appropriate horizontal line, and their heights read as the lowest level of the lens on the lower, horizontal line scale.

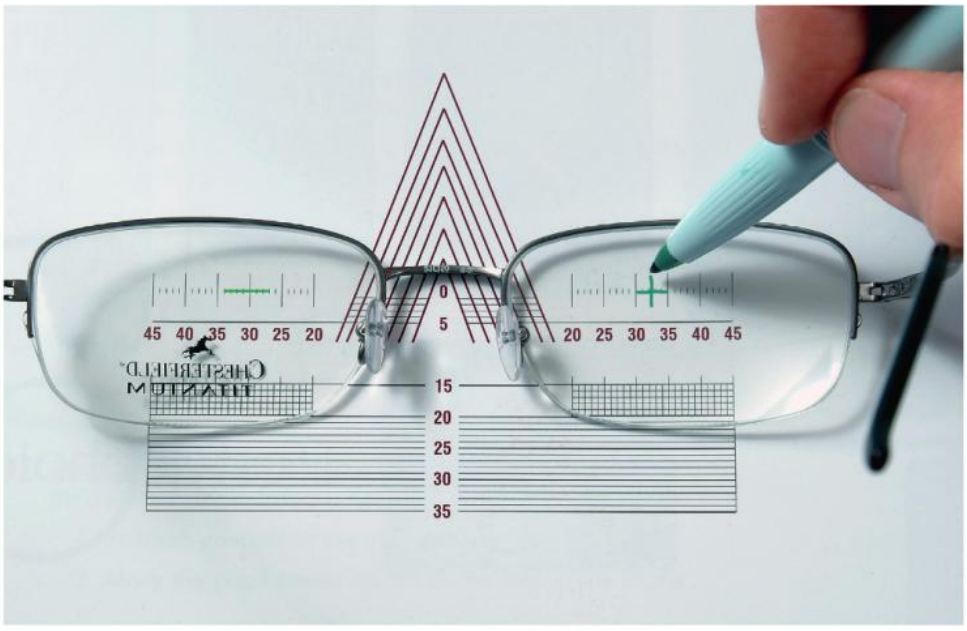

Figure 20.4 In preparation for checking whether a lens blank will be large enough for the frame chosen, the wearer's previously measured monocular interpupillary distances are marked on the lens.

Fitting Cross Heights for Children

Presbyopia, the natural aging process in which the crystalline lens within the eye becomes nonelastic, is why middle-aged adults can no longer see near objects clearly with their habitual distance correction alone. Progressive addition lenses restore clear vision at intermediate and near working distances for these patients, which explains why nearly all progressive lens wearers are adults. However, as discussed in Chapter 5, bifocal lenses and progressive addition lenses are occasionally used for children to treat eye alignment problems such as accommodative esotropia, and it involves altering the segment or fitting height from its usual position.

Presbyopic adults have no choice but to view through the near addition to experience clear vision while viewing near objects. In contrast, children can experience clear vision at near distances with or without the near addition. In cases in which the near addition is needed for the treatment of eye alignment rather than presbyopia, it is imperative that the segment height or fitting height be positioned in a way that forces the child to look through the near addition while viewing near objects, and this is achieved by setting the near addition higher in the lens than normal.[4] It is recommended that progressive addition lenses be fitted 4 mm higher than the center of the pupil for children ages 7 years or younger. For children ages 8 years or older, a fitting height of 2 mm

BOX 20.1 Important Considerations for Progressive Addition Lens-Fitting Heights

1. Though specified by the manufacturer, the *minimum fitting height* is normally considered to be the distance from the fitting cross to the center of the NRP.
2. Being right at the minimum fitting height may cut off up to half of the near viewing area or more.
3. For best results, the height of the fitting cross should exceed the manufacturer's minimum fitting height by at least 2–3 mm.
4. Trying to go below the minimum fitting height by increasing the add power of the lens will not work.[2]
5. Raising the height of the fitting cross to allow for more fitting height may work if there still remains enough distance between the fitting cross and the top of the lens. The best fitting height strikes a balance between distance and near viewing.
   a. The distance reference point (DRP) is about 4 mm above the fitting cross, depending on design. The area immediately surrounding the DRP is where best distance vision occurs. So ideally there should be at least 9 mm from the fitting cross to the top of the edged lens.
   b. The best policy is to use the frame with the fitting cross location marked on the demo lenses and place it on the manufacturer's centration chart. The chart shows the distance and near reference circles. Both should be within the frame's lens opening.
6. When the desired frame does not allow enough fitting height, and if there is not as much need for intermediate viewing, switch to a short corridor progressive lens.
7. If there is not enough fitting height available with the selected lens design, consider switching to a higher end, free-form progressive lens design with a variable corridor length.
8. If the new frame has a greater vertical dimension than the previously worn frame, consider the following advice:
   a. "Stay with a satisfactorily worn corridor length when you can, and place the fitting cross location relative to the pupil as it was in the previous eyewear. Even if the B measurement is deeper than with the previous eyewear, keeping its length the same will often allow for easier adaptation and a more satisfactory outcome.
   b. Variable length corridors seem to be the industries' attempt to avoid cutting off the lower part of the NRP zone, or near sweet spot. Some patients who have gone to deeper frames with variable length corridors have found the increased down-angle to use the NRP area to be both inefficient and annoying."[3]

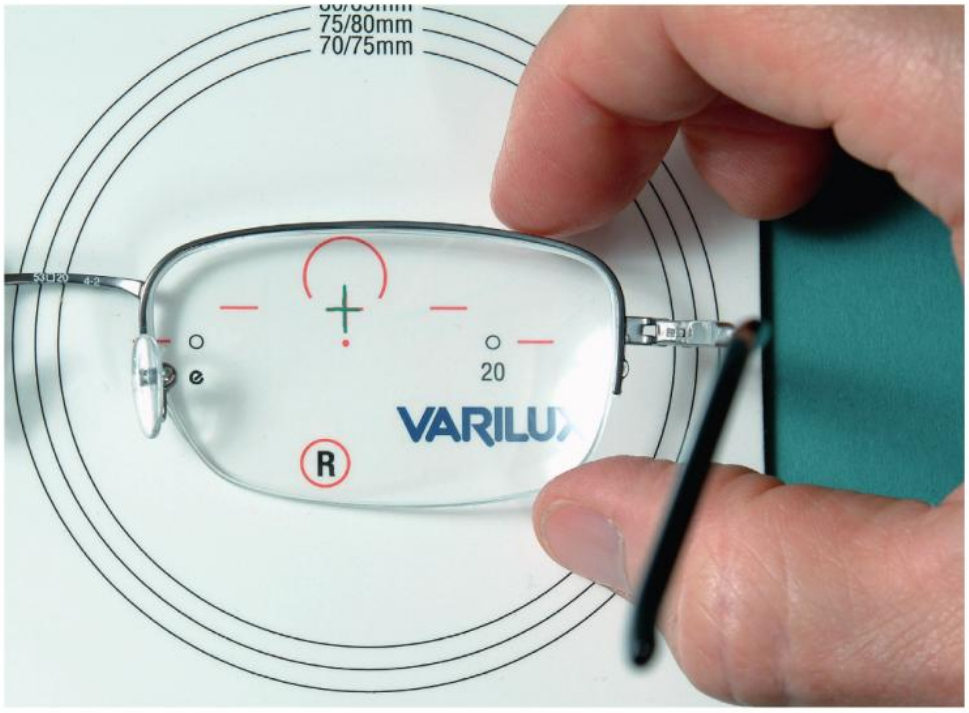

Figure 20.5 To see if the lens blank will be large enough for the frame, the fitting cross that has been drawn on the glazed lenses is placed over the fitting cross in the picture of the lens blank. The smallest lens size that completely encircles the edged lens or lens opening is the minimum blank size needed. If the largest pictured lens blank size fails to encircle the edged lens or lens opening, the frame is too large for the proposed lens. A different frame must be selected.

higher than the center of the pupil is recommended.[5] As children approach the teen years, more consideration is given to setting the fitting height at the typical adult level.

Kowalski et al. compared the adaptability of 235 myopic children wearing progressive addition lenses with 234 myopic children wearing single-vision lenses. The progressive addition lens wearers were fit with the fitting cross 4 mm above the pupil center, and the study concluded that most children were able to successfully adapt to such fitting heights without any interference to their visual demands in the classroom, while using the computer, or for physical activities such as playing sports.[6]

The only time a child would not be fitted higher than pupil center would be if the child has no intraocular accommodation, as after cataract surgery.

Alternative Methods for Taking Progressive Lens-Fitting Measurements

Marking a Cross on Glazed Lenses or Tape

Sometimes a pupillometer is not available for measuring monocular PDs. If this is the case, here is a method that uses only a marking pen and the frame:

1. Fully adjust the frame to fit the wearer correctly.
2. Position yourself at the same level as the wearer and approximately 40 cm away.
3. Close your right eye and instruct the wearer to look at your open left eye.
4. Use the marking pen to mark a cross on the right lens. If there is no lens in the frame, place clear tape across the lens opening and mark the tape instead. Draw the cross directly over the center of the wearer's right pupil.
5. Next close your left eye, open your right eye, and instruct the subject to look at your open eye. Then mark a cross on the lens or tape directly over the left pupil center.
6. Because of the movement involved in marking pupil centers and the ease with which unintentional head movement can occur, it is important that these markings be carefully rechecked. If the wearer turns the head slightly to one side, an error in monocular PDs will occur. It may be hard to catch this error since both monocular PDs may be slightly off but still add up to what would otherwise be a correct binocular PD.
7. When you are confident that pupil centers are accurately marked, remove the frames. Measure and record the distances from the center of the bridge to the center of each cross using the progressive lens manufacturer's centration chart.

For those who prefer to use corneal reflections instead of the geometric center of the pupil, a penlight positioned directly below the dispenser's open eye will provide the source for the needed reflection.

Using the Red Dot Procedure to Subjectively Verify Fitting Cross Positions

To subjectively verify the position of the fitting cross, use the preceding method, but either substitute a red dot for the cross or draw a red dot in the center of the cross. When measurements are complete, ask the wearer to look straight ahead and view a distant object. The object should appear pink if the wearer is correctly viewing through the red dots. First one eye and then the other is covered. If the wearer must move the head to see pink with either or both eyes, the lenses need to be remarked.[7]

VERIFYING A PROGRESSIVE LENS

Major Points or Areas

When the glasses are returned from the laboratory, they contain removable markings, such as a distance power arc, the fitting cross, horizontal dashes, and a prism reference point (PRP) dot. It may or may not contain a near-point power circle (Figure 20.6). The distance power arc indicates the recommended position of the lens through which the distance power should be read on the lensmeter.

- The DRP is at the center of the arc.
- The fitting cross will normally be centered in the pupil.
- The two horizontal dashes to the left and right sides of the lens help to tell if the lens is level or tilted.
- The centrally located PRP dot is used to verify prism power.
- The circle shown in the lower part of the lens locates the near reference point (NRP) and is used to verify near power. There may not be a circle present.

It is preferable that these markings on the surface of the progressive lens be left on the lens until the finished prescription is both verified and fitted on the patient. This enables the dispenser to verify the powers at far and near and to more easily judge the accuracy of the positioning of the lenses on the wearer's face when the frame is finally adjusted. When the temporary markings are gone, they can be reconstructed using semivisible surface engravings called *alignment reference markings* (*ARMs*)

Verifying Distance Power, Prism Amount, and Add Power

Verifying Distance Power

The distance power of a progressive lens should be measured through that portion of the lens that is marked by the distant power arc or circle positioned in front of the lensmeter aperture (Figure 20.7). The place where distance power should be measured is set by the manufacturer and is known as the *distance reference point* (DRP). It should be noted that the positioning of the lens is a top source of error when measuring progressive lenses.[8]

Verifying Prism

Prism, however, is measured at the specified location of the *prism reference point* (PRP) (Figure 20.8), even though the target may be slightly blurred. The target may be blurred in the lower half of the viewing field because the progressive corridor begins at the PRP.

Prism is verified in the same manner as for other lens pairs as was described previously in Chapter 6 on Ordering and Verification. However, there is one notable difference. Progressive lenses may be made thinner using a prism-thinning technique that usually consists of yoked base-down vertical prism. In other words, the same amount of base-down prism is applied to both lenses. This way lens thicknesses may be reduced without disturbing binocular vision. (Prism thinning is described in greater detail later in this chapter.)

Because yoked base-down prism will appear at the PRPs, unwanted vertical prism is the difference in right and left vertical prismatic effects. If both lenses read 1.50Δ base down at their PRPs, there is zero unwanted vertical prism. However, if the right lens reads 2.50Δ base down and the left lens reads 1.50Δ base down, the net vertical prismatic effect is 1.00Δ base down for the right eye. (This could alternately be expressed as 1.00Δ base up for the left eye.)

If vertical prism base directions for both lenses are the same, subtract them from one another to find the net vertical prismatic effect. If vertical prism base directions are opposite, then add them together to find the net vertical prismatic effect.

Verifying Progressive Add Power

As can be expected in all types of multifocal lenses, the near portion of progressive lenses will demonstrate power in an amount dependent on the power of the distance portion and add. The near power should be read through the area located according to the manufacturer's specified location. Previously, this area was identified by a circular marking around the center of the near power area, but it is now usually unmarked (Figure 20.9). This near point location, set by the manufacturer, is referred to as the *NRP (near reference point).*

Figure 20.9 shows the near addition being measured as back vertex power. However, the same rules that apply to standard multifocal lenses should also be followed to determine the add for progressive lenses.

When the progressive optics are on the *back* surface, measure the add using the difference between distance *back* vertex power and near *back* vertex power as was shown in Figures 20.7 and 20.9. When the progressive optics are on the *front* surface of the lens, measure the add using the difference in *front* vertex powers as shown in Figure 20.10, *A* and *B*.

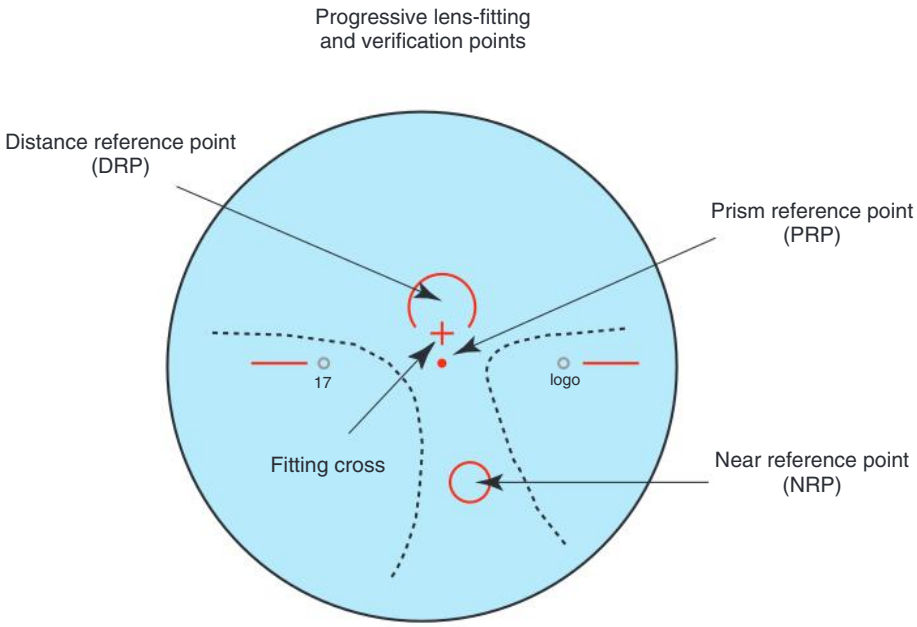

Figure 20.6 In verifying a progressive addition lens, the distance power is verified higher on the lens than it would ordinarily be on other lenses. The manufacturer determines where it should be verified, calls it the *DRP,* and marks the DRP location with an arc or parentheses. Prism is verified at the *PRP*. The add power is verified at the location set by the manufacturer. It is called the *NRP* and may or may not be marked with a circle. No power or prism verification is done at the fitting cross.

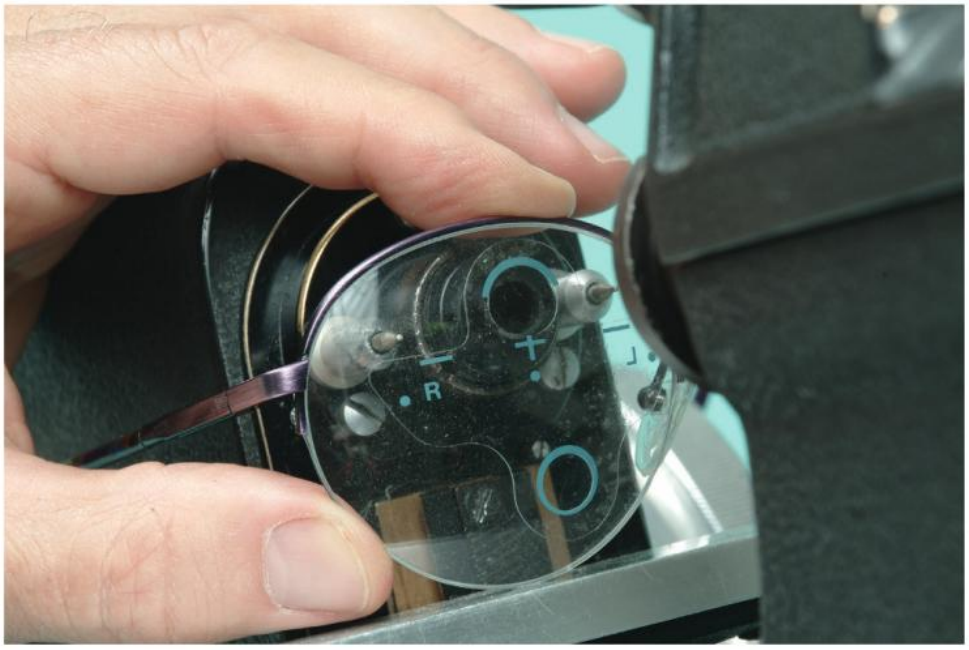

Figure 20.7 To verify distance power on a progressive addition lens, the lens must be positioned with the arc around the lensmeter aperture as shown. This ensures that the power reading will not be affected by the changing power in the progressive zone.

Some progressive addition lenses split the progressive optics of the add between both front and back surfaces. In this case, follow the lens manufacturer's recommendations for how to measure the add power.

In practice the power of the near addition is seldom measured for progressive lenses. This is because near addition power appears as a semivisible number on the front surface of the lens. Instead of using the lensmeter to find add power, verification is done by finding this number.

Verifying Fitting Cross Height and Monocular Interpupillary Distances

Fitting cross height and monocular PDs may be checked by centering the bridge of the glasses on the diagonally converging central alignment pattern of the manufacturer's centration chart. The horizontal lines on the lens must be on (or parallel to) the horizontal axis of the centration chart with the fitting cross height at the "zero" level. From this position, the monocular PDs and fitting cross heights can be verified.

Figure 20.8 To verify prismatic effect, the lens is verified at the prism reference point located by the central dot directly below the fitting cross.

Figure 20.9 When the near progressive addition power is on the *back* of the lens, then the correct way to verify near power with the lensmeter is to first find the back-vertex distance power as was shown in Figure 20.7. Next, find the near back vertex power as shown in this photograph. The near addition power is the difference between these two measures.

It is important to locate the semivisible engravings called *alignment reference markings* (ARMs) on the lens as well (Figure 20.11). This will ensure that the lens is indeed properly marked. It is not unusual for the laboratory to have to reapply the visible markings if they were removed during processing. If the visible markings appear correct but the alignment reference marks (ARMs) do not coincide with them, the ARMs are what should be used in verification.

Locating the Alignment Reference Markings on a Progressive Lens

All progressive lenses have similar semivisible markings or engravings on their surfaces. These markings are directly used to identify the manufacturer, the design, and the add power. They are used indirectly to reconstruct the removable markings that allow distance power, PRP, and near power to be found. The semivisible engravings

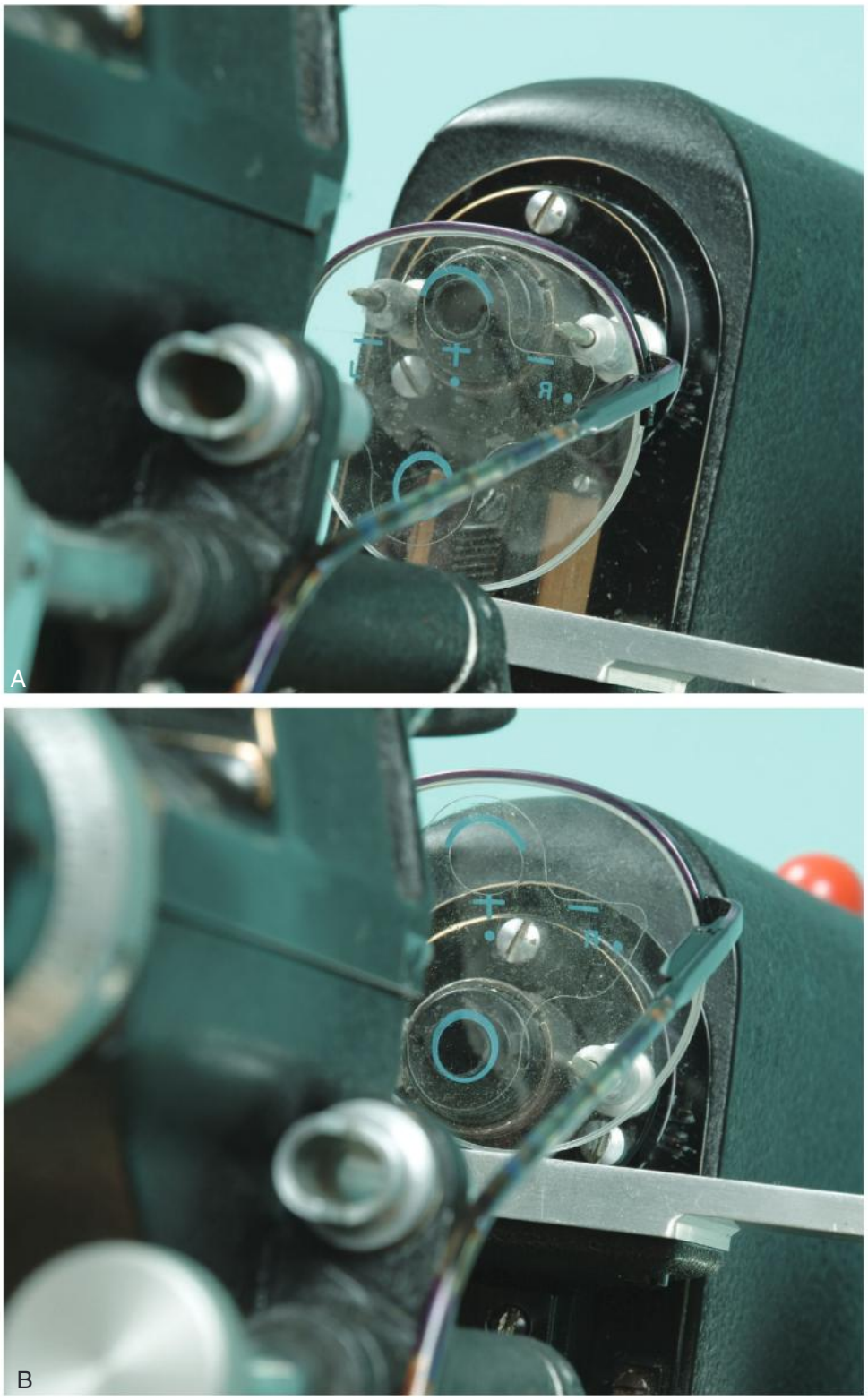

Figure 20.10 For conventionally surfacing progressive addition lenses, the semifinished lens comes with the progressive addition power on the front of the lens. When the add power is on the front of the lens, the add power (not the distance power) is measured using front vertex powers. This is no different from any other multifocal lens. **A**, The front vertex power is measured through the distance portion as the first step in obtaining an accurate add power. **B**, The second step in accurately measuring the add power is to measure front vertex power through the near portion. This difference between distance and near front vertex powers is the power of the near addition.

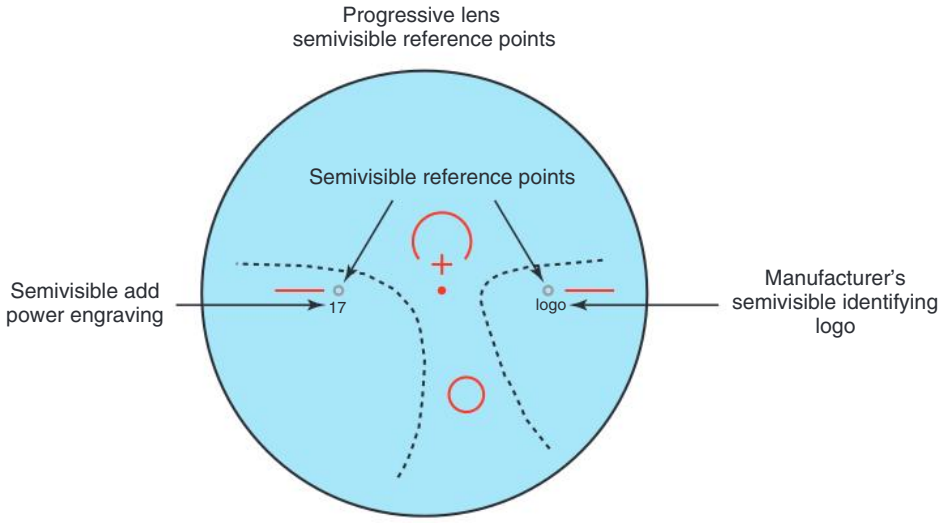

Figure 20.11 Manufacturers place semivisible marks on the front surface of a progressive lens for four reasons: (1) to identify their product so that the dispenser is certain the product is the brand ordered, (2) to identify unknown lenses already being worn, (3) to indicate add power, and (4) to provide reference points to allow the reapplication of removable markings for verification purposes. These reference points may be called alignment reference markings (ARMs) and are approximately 34 mm from one another. In this illustration, the number 17 indicates a +1.75 D add power.

that allow reconstruction of temporary markings are found in the forms of circles, squares, triangles, or trademark symbols at lateral positions on either side of the lens.

On most brands, the power of the add is engraved 4 mm below the temporal symbol, although it may be above that symbol on some. On most brands, a mark identifying the design or the manufacturer is engraved 4 mm below the nasal symbol.

These semivisible engravings are hard to see. The following three sections discuss methods that may help dispensers locate them.

Use a Black Background

Using a black background, hold the lens so that there is plenty of light on it. It is often helpful to locate the light source on the other side of the lens, off to the side or above it. Tilt the lens to inspect the lens surface from different angles until the markings become visible.

Use a Fluorescent Bulb

It may be possible to find the markings on a lens by using a fluorescent light source behind the lens. To use this method, hold the lens up with a fluorescent ceiling light in the background, and view the lens surface.

Use an Instrument to Find the Semivisible Engravings

The Essilor instrument for finding these markings consists of a magnifier and an illuminated area for the lens. This facilitates lens identification in a controlled manner (Figure 20.12). Markings are considerably easier to see because they are clearer and appear larger. Figure 20.13 shows a view of what these markings look like through this instrument.

Identifying an Unknown Progressive Lens

When someone is wearing a progressive lens and the lens manufacturer, lens design, or lens material of the progressive is unknown, the semivisible markings will reveal the needed information. Remember that normally a marking identifying the design is engraved 4 mm below the nasal circle or symbol. To "decode" these markings, look in the Vision Council's *Progressive Identifier* available on their web site at *epic.thevisioncouncil.org* as an *Electronic Progressive Identifier Catalog (EPIC)*. It is also available for download. This resource

Figure 20.12 This Essilor instrument allows the markings on a progressive addition lens to be seen much more easily than with the naked eye. The open placement of the lens on the instrument means that the markings can be dotted with a marking pen while looking through the instrument.

shows pictures of each type of progressive lens with all their semivisible markings. The *Progressive Identifier* gives information on lens type, material, fitting cross location, and minimum recommended fitting height.

Remarking a Lens Using the Alignment Reference Markings

To remark a lens, the two engraved alignment reference circles (or markings) can be emphasized by dotting their centers with a nonpermanent, thin felt-tip or fiber-point pen. These dots are then placed on the respective manufacturer's centration or verification chart. Other removable markings for power control circles, fitting cross, and PRP can be traced onto the lens using the chart as a guide.

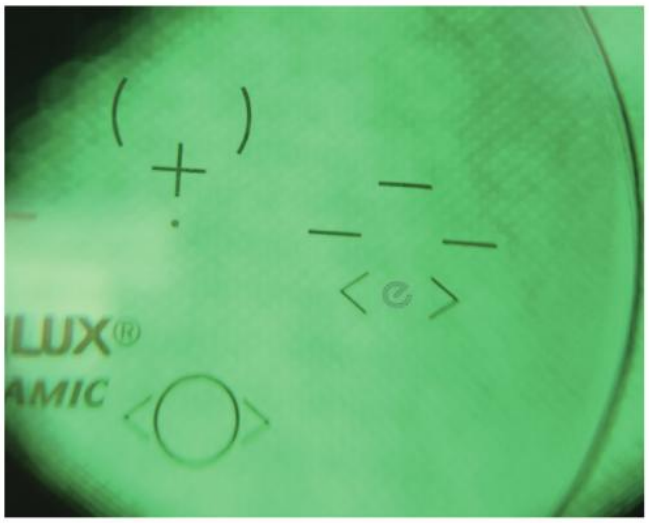

Figure 20.13 This photo shows the permanent, semivisible marking on a progressive addition lens using the Essilor instrument. The permanent lens identification logo is found between the nonpermanent, caret marks. (The photographic view through the instrument as seen in this figure has been retouched for clarity.)

BOX 20.2 Checking the Near Viewing Area for Progressive Addition Lenses

Checking for the Near Viewing Area

If a person has an especially small interpupillary distance (PD), or *if you are concerned that the near viewing area may not come out right*, it is possible to check ahead of time using the following steps:

1. Measure for monocular distance PDs and fitting cross height.
2. Mark the sample lenses that are in the frame with these measurements.
3. Use the lens manufacturer's centration chart to locate the proposed location of the near lens power. This area is identified with a circle on the chart.
4. Use a marking pen to trace the circle on the lenses.
5. Close one eye, position a penlight directly under the open eye, and point the penlight at the wearer's eyes. (You should be at the wearer's normal near working distance, which is usually 40 cm, or 16 inches.)
6. Instruct the wearer to look at your open eye. Place your fingers under the wearer's chin and tilt the chin back until the eyes can be seen through the drawn circles.
7. If the circles are not centered, you will need to adjust the PD so that the circles will be centered.

To evaluate *the problem of a new progressive lens wearer complaining about a small near viewing area*, find the alignment reference markings (ARMs), which are often circles on the lens. Using these ARMs, trace the fitting crosses and near circles back on the lenses. Follow steps 5 through 7 above.

DISPENSING PROGRESSIVE LENSES

Validation on the Wearer

Once the prescription has been proven to be correct, the glasses are adjusted to fit the wearer. Normal frame fitting rules apply. In addition, to provide the maximum possible field of view, adjust the frame for:

1. A small vertex distance
2. Adequate face form
3. A maximum pantoscopic tilt that still looks appropriate for the wearer

With the removable markings still on the lenses, also check the following:

1. The horizontal dashes on the lenses should be exactly horizontal and not tilted.
2. The fitting crosses should be in front of each pupil center. (The placement of the fitting crosses is especially important when the two eyes are not at an equal vertical height.)

By having the wearer look at the dispenser's open eye, tilt the wearer's chin upward. At the level of the near reference circles, the wearer's eyes should be looking through the circles. If near reference circles are not marked, they may be added by using the manufacturer's centration chart. (If there is a concern about the near viewing area before ordering, it is possible to check ahead of time by following the steps shown in Box 20.2.)

Eliminating the Removable Markings

The removable markings that are on a progressive addition lens when it comes back from the laboratory are nonwater soluble. To remove them, use alcohol, an alcohol swab, or a removal fluid available from an optical supplier. These marks can be stubborn. Some say that difficult-to-remove markings may come off easier if the lens is first heated with a hot air frame warmer.

Instructing the Wearer at Dispensing

Adapting to progressive lenses can be made easier for a new wearer if the characteristics of the lenses are demonstrated at the time they are dispensed.

To demonstrate the full range of progressive lens versatility, hold a near-point chart at eye level at an intermediate distance. Instruct the wearer to look directly at the near-point card through the distance portion. Next ask the patient to tilt his or her head back until the letters on the card are clear. Gradually, bring the card closer to the eyes as the head is tilted still farther back, demonstrating the full range of viewing available.

More head movement is required with progressive lenses. Therefore, some fitters recommend instructing the wearer to first point his or her nose at the object to be seen, then to move the head somewhat up or down until things clear.

Attention should also be called to any distortion present during peripheral gaze so the wearer understands that this is to be expected. While the wearer holds the head still, demonstrate areas where vision is not as clear by moving the near-point card to the left and right in the reading area while the wearer follows the card with the eyes. As observed in some studies, adjustment to distortion and increased head movement are adaptations that depend on steady wear of the lenses. In other words, wearing the lenses at all times will speed the adaptation process. Emphasize this point to the new wearer.

Once again remember that it is better to point out any areas of distortion rather than having the wearer "discover" them and report back with a problem. If this lens characteristic is pointed out ahead of time, the dispenser is considered to be knowledgeable when it occurs. If the wearer discovers the problem and points it out, the dispenser is in the awkward position of having to explain after the fact.

TROUBLESHOOTING PROGRESSIVE LENS PROBLEMS

Most problems encountered by progressive lens wearers are a direct result of basic fitting principles being ignored. Here are a few typical errors that should never occur but do.

- One monocular PD is correct; the other is wrong. This happens when the monocular PDs are done with a ruler or by marking the PD measurements on the lenses, and the fitter uses only one eye to measure both lenses.

- The PD is given as a binocular PD or measured as a binocular PD, then divided by two. The PD should be measured and recorded as two independent monocular PDs.
- Fitting cross height is measured for one eye, and the same measurement is written down for both eyes. Fitting cross heights must be individually measured for both eyes.

When a wearer does come back with a complaint, the most straightforward way to check for possible problems is to ***first*** put the removable progressive markings back on the lenses and see if they are correct in relation to where they should be when the prescription is worn. Often the problem will be obvious.

If the solution is not immediately apparent, Table 20.1 gives many common complaints, reasons they occur, and possible solutions.

SECTION 2: GENERAL PURPOSE PROGRESSIVE LENSES

OPTICAL CHARACTERISTICS OF GENERAL PURPOSE PROGRESSIVE LENSES

The first successful progressive addition lenses were designed to maintain some of the characteristics of bifocal lenses. One criterion considered to be important was maintaining traditional lens optics in the upper half of the lens. When this was done, the power from the midline upward corresponded exactly to the prescribed distance power. At the midpoint of the lens and downward, following the expected path of the eyes, plus power began to increase. Once the

TABLE 20.1 Troubleshooting Progressive Addition Lens Problems

Complaint	Possible Causes	Possible Solutions
Distance vision is clear, but there is not enough vertical distance viewing area.	1. The fitting cross is in front of the eye, but there is less than 8 mm between the fitting cross and the top of the lens.	A. Select a different frame with more distance between the pupil and the top of the lens and reorder. B. Reordering new lenses for the same frame with the fitting cross positioned lower than it was before is not recommended. This kind of a change should only be done with caution, recognizing how intermediate and near viewing will be affected.
The wearer has to lower the head to drive or see well in the distance.	1. The fitting cross is too high. The wearer is looking through the beginning of the progressive zone.	A. Adjust the frame to lower the fitting cross. B. Remeasure the fitting height, and reorder the lenses.
Central distance vision is blurry.	1. The fitting cross is too high. The wearer is looking through the beginning of the progressive zone. 2. The distance refraction is off.	A. Adjust the frame to lower the fitting cross. B. Remeasure the fitting height and reorder the lenses. A. Recheck the refractive prescription.
Distance vision is clear in the center but blurry on either side (in the periphery).	1. The vertex distance is too large. 2. The lens is a soft design, and the vertex distance is too great. 3. The wearer has little or no distance prescription, and the lens has a soft design with some distortion in the distance periphery. 4. The lens has been made on the wrong base curve.	A. Decrease the vertex distance. B. Increase the face form (wrap-around) of the frame. A. Adjust the frame to decrease the vertex distance. A. Change to a harder design with less peripheral distortion in the distance. A. Check to see if the base curve is what is recommended for the distance power of the lens.
There is not enough width for intermediate viewing distances, or the intermediate vision is not clear.	1. The monocular distance PDs are incorrect. 2. The fitting heights are too low or high. 3. The lenses are not fit close enough to the wearer's eyes. 4. The lens design is too hard. 5. Add power is over-plussed (too high). 6. The wearer's needs for intermediate viewing are too great for a general-purpose progressive lens.	A. Remeasure for monocular PDs, and, if incorrect, remake the lenses. A. Adjust the frame for the correct fitting height. B. Remeasure the fitting cross heights, and remake the lenses. A. Adjust the frame for a closer vertex distance. B. Increase the face form of the frame. A. Use a lens with a softer design. A. If add power is greater than would be prescribed normally, reorder and correct the add power. A. Suggest a second pair using an occupational progressive lens.
The wearer has to tilt the head back or raise the spectacles for reading.	1. Either the fitting crosses are too low or the progressive corridor is too long for the frame. 2. The add power is too weak.	A. Adjust the glasses to raise the frame on the face. B. Remake the lenses for a different fitting height to use a shorter corridor lens design. (Note: This will also affect the intermediate viewing length and width.) A. Remake the lenses.
Near viewing area is too small and/or near vision is poor.	1. The lens-to-eye (vertex) distance is too great.	A. Adjust the frame to decrease the vertex distance so the frame fits closer to the face. B. Adjust the frame to increase the frame face form (wrap-around).

Continued

TABLE 20.1 Troubleshooting Progressive Addition Lens Problems—cont'd

Complaint	Possible Causes	Possible Solutions
		C. Increase the pantoscopic angle to bring the lower half (near viewing area) of the frame closer to the face.
	2. The wearer has not been instructed on how the lens is to be used.	A. Instruct the wearer on how to use the lenses, and see if he or she recognizes the appropriate area of the lens to use for near viewing.
	3. One or both of the monocular PDs are incorrect. The eyes are not in the center of the reading portion, narrowing the useable reading area.	A. Remeasure for monocular PDs and remake lenses.
	4. The lens or frame is fit too low.	A. Adjust the frame to move it higher on the face. B. Remeasure and remake the lens.
	5. The vertical dimension of the frame is too small for the progressive lens, and too much near viewing area is being cut off.	A. Use a frame with deeper vertical dimension. B. Use a short-corridor lens design appropriate for frames with narrower vertical depths. C. DO NOT increase the add power in an attempt to avoid or correct this problem!
	6. The add power is incorrect.	A. If the add power is too high, the correct power will not be found in the normal near viewing area. (Note: This is a common problem for those who think that progressive lens add power should be higher than would be prescribed for segmented multifocal add power.) B. Recheck the refraction, and reorder the lenses if necessary.
	7. The lens design has insufficient width for the near viewing needs of the wearer.	A. Choose a lens design with a wider near area. B. Suggest a second pair of occupational lenses for a small office environment.
	8. The monocular *distance* PDs are correct, but the monocular *near* PDs are either too large or too small.	A. Measure monocular *near* PDs. Add the manufacturer's segment inset to the newly-measured monocular near PDs. Order these values as monocular distance PDs.
The wearer has to hold the reading material to one side in order to read.	1. The monocular PDs are probably off.	A. Remeasure each lens separately, and remake the lenses to the correct monocular PDs.
	2. Check to see if the wearer has a previously unnoticed head turn.	A. Remeasure PDs with the head in the habitually turned position.
	3. The left and right distance lens powers are considerably different.	A. If anisometropia is present, consider a binocularly designed lens pair with variable inset.
The wearer has to tilt the head back in order to read.	1. The lenses are fit too low.	A. Adjust the frame so that it sits higher on the face. B. Remeasure and remake the lenses.
	2. The progressive corridor is too long for the wearer.	A. Go with a shorter corridor progressive lens.
Objects in the periphery seem to move or "swim" when the wearer is moving around.	1. The lenses are not fit close enough to the wearer's eyes.	A. Adjust the frame for a closer vertex distance. B. Increase the face form (wrap-around) of the frame.
	2. The lens is a "hard design," and/or the add power is higher than the previous glasses.	A. Switch to a softer lens design or a higher end free-form lens design.
To see objects clearly for intermediate and near distances, the wearer needs to move the head more than would be expected.	1. The lenses are not fit close enough to the wearer's eyes.	A. Adjust the frame for a closer vertex distance. B. Increase the face form of the frame.
	2. The add power is too high.	A. Recheck the near add power, and remake the lenses for a lower add power.

Data from Enhancing patient satisfaction with Varilux Comfort, video #306-922043, 0399-CP, Essilor of America, St. Petersburg, FL; Brown WL: Progress in progressive addition lenses, 2001 Ellerbrock memorial continuing education program, Philadelphia, PA, 12/6/2001, pp. 303–306; Reference Guide 2002, LPAN200009 05/02CP, Essilor of America; Meister, Darryl, Progressive Lens Dispensing, Module 10, OptiCampus, 2008.

full add power was reached, lens power did not vary. The progressive zone connects distance and near lens areas. These types of lenses are said to have *spherical upper halves* because the front surface of the upper half of the lens is spherical rather than aspheric.

The first really successful progressive lens designed this way was the original 1959 Varilux lens.[9]

Unwanted Cylinder

Unwanted cylinder is the greatest problem inherent in progressive addition lenses. Although the progressive zone gives clear vision when properly fitted and dispensed, the areas to either side of this zone will have some unwanted cylinder power. This cylinder varies in amount and orientation depending on lens design and add power. It will be

more noticeable if the eye moves far enough laterally from within the progressive zone.

A Sandbox Analogy

There are certain design characteristics that change the amount of unwanted cylinder in the periphery of the lens. To help understand how this works, we will use an oversimplified example of a sandbox. Think about a round sandbox with the surface of the sand smoothed to a spherical shape to resemble the front surface of a regular, single-vision lens. Suppose we want to change the surface curvature of one area of the sand. The object is to give the surface a new "power" so that it will resemble the near portion of a progressive addition lens.

We can do this by starting at the center and gradually increasing the curvature of the surface in a certain area corresponding to the progressive portion of a lens. In other words, we start shaving the surface of the sand, removing sand from that area. But one of the first sandbox rules is, "You are not allowed to throw sand out of the sandbox." (Keep in mind that this is an analogy only and is not what really happens with progressive lenses. It is only meant to characterize the problems faced by lens designers.) So where do we put the sand? If we wanted to keep the upper half of the lens at exactly the distance power, it could not go there. Sand would have to be piled on either side of the progressive zone and then smoothed out. This changes the curve of the surface and causes unwanted cylinder.

Interrelating Progressive Lens Design Factors

Here are some general design factors that may influence unwanted cylinder power and other lens parameters.

1. *Add power*—as add power increases, so will the amount of unwanted peripheral cylinder.
2. *Rate of progressive power change*—progressive power can change from distance to near zones in either a rapid or slow fashion, making the progressive corridor either short or long. A rapid change means that the progressive zone surface curvature changes over a very short distance, resulting in a short corridor lens.

   When the power changes rapidly,
   - The intermediate zone width will generally be smaller.
   - The near zone is generally wider and larger.[10]

   If the progressive zone is longer, the plus power changes more slowly. A longer progressive zone means less unwanted cylinder; a shorter progressive zone means more unwanted cylinder.
3. *Intermediate zone width*—a larger minimum intermediate zone width is associated with lower amounts of unwanted cylinder.[11] The smaller the intermediate zone width and area, the greater the unwanted cylinder will be. However, there is not as direct a relationship between the amount of unwanted astigmatism and near-viewing zone size.
4. *Zone widths*—distance, intermediate, and near zone widths influence each other. When one zone is made larger or wider, the other two zones will become narrower and smaller.[10]

The Use of Contour Plots to Evaluate Progressive Lenses

In 1982 a standard format was initiated for representing the surface characteristics of progressive addition lenses. This took the form of connecting points having equal powers. The concept is similar to that of topographic maps that show mountainous heights. These line diagrams are known as *contour plots.*

One form of contour plot maps the amounts of unwanted cylinder power, showing how fast cylinder power increases over the lens surface. Areas of equal cylinder power are plotted with a connecting line. These lines are called *isocylinder lines* (Figure 20.14, *B*). Another type of contour plot maps areas having equal spherical equivalent powers (see Figure 20.14, *A*). With these it is possible to see:

1. How fast the power increases in the progressive corridor
2. What kind of power changes take place in the upper and lower lens peripheries

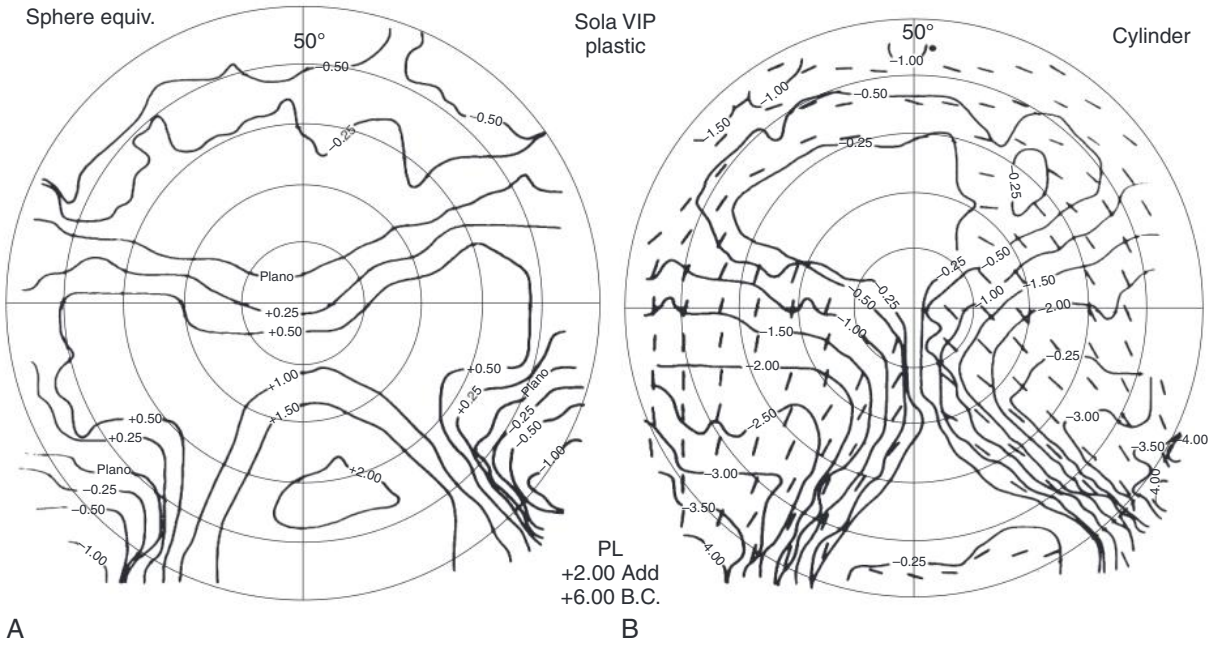

Figure 20.14 The contour plot in **A** shows changes in lens power plotted as the spherical equivalent. The contour plot shown in **B** is plotted as unwanted cylinder alone. Both plots are of the same lens having a plano distance power and a +2.00 add power. (From Sheedy JE, Buri M, Bailey IL, et al. Optics of progressive addition lenses. *Am J Optom Physiol Optics* 1987;64:90–91, Figure 1.)

Being able to read contour plots allows for a greater understanding of the features common to all progressive lenses and the individual characteristics that may differentiate one lens design from another. It should be understood, however, that contour plots may not be depended upon to precisely convey a given lens' actual performance when being worn. Clinical choices made by progressive addition lens wearers may not agree with predictions anticipated from contour plots.

Contour plots do demonstrate relative progressive zone width, the presence of a hard or soft optical design, and the anticipated amount of unwanted cylinder in the upper half of the lens. They may also be helpful in matching a certain style of progressive addition lens to the optical needs of the wearer.

HOW PROGRESSIVE LENS DESIGNS HAVE CHANGED

We would not expect today's progressive addition lenses to be the same as they were when first successfully used. Progressive lens designs come forth as a result of professional judgments as to what lens characteristics are most important when worn. These judgments do not always agree. In addition, one philosophy may be correct for one wearing situation but not for another. Here are some of the contrasting ways lenses have been designed.

Spherical and Aspherical Distance Portions

Originally, progressive lenses were designed to maintain an upper half just like a regular single-vision lens. The upper half had a spherical front surface (Figure 20.15). In 1974 Varilux introduced a design called the Varilux 2 or Varilux Plus. This design attempted to reduce the intensity of unwanted cylinder by spreading it out over a larger area. It soon became evident that small amounts of induced astigmatism could be tolerated in the periphery of the distance portion. Lenses designed in this manner are aspherical in the upper *and* lower portions of the lens surface instead of just in the lower section, containing the progressive corridor (Figures 20.16 and 20.17). Returning to the oversimplified sandbox analogy, we can see that in allowing the displaced "sand" to be spread over a larger area, the amount of unwanted cylinder in any given area will be reduced. Usually a lens with a spherical upper half resembles a "hard" design and one with an aspherical upper half, a "soft" design. These terms will be explained shortly.

Hard Versus Soft Designs

When an individual wearing a progressive addition lens is using the near-viewing area of the lens and slowly looks to one side, the eyes begin to leave the region of the near zone. Outside of this near zone, the power begins to change, and unwanted cylinder power increases.

Hard Designs

With a bifocal lens, there is a distinct, lined border between the near-viewing area and the rest of the lens. There is no question as to where the near portion ends. With some types of progressive addition lenses, the change in power and increase in astigmatism is more demarcated than in others. For example, the unwanted cylinder may rapidly increase from nothing up to 0.50 D and then move quickly to 1.00 D, and on up to 1.50 D in the space of only a few millimeters. Because of the rapid change along the border between viewing areas, this type of design is known as a *hard design* (Figure 20.18).

Hard designs generally offer larger and more delineated areas of unvarying optical power for distance and near viewing. Often in hard designs, the power in the progressive channel increases rapidly. When a person looks down, the eyes reach the level of full add power sooner.

The disadvantages of hard designs are linked with the rapid increase in cylinder power and the areas in which that unwanted

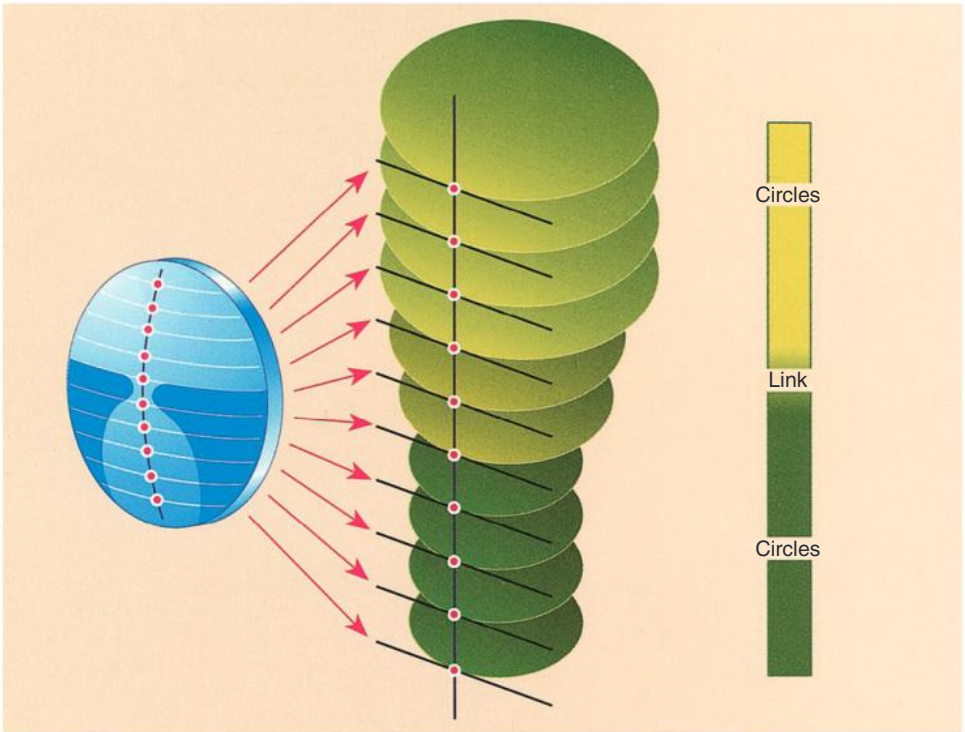

Figure 20.15 The original Varilux lens was designed to maintain a spherical surface in the upper half of the lens. It had two large and spherical distance and near vision zones linked together. (From Progressive addition lenses, Ophthalmic Optics File, p. 28, Figure 25, Essilor International, Paris France, undated publication.)

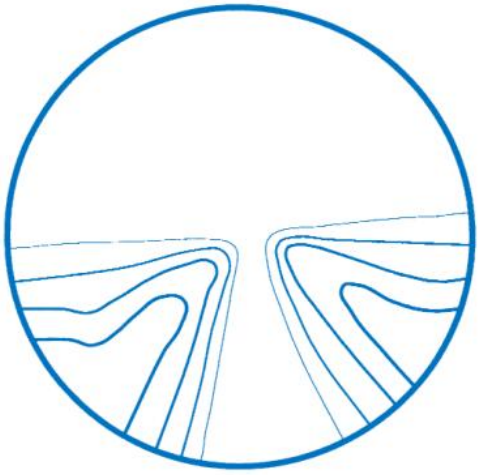

Figure 20.16 This simplified contour plot shows a lens with a spherical upper front surface. The concentric lines represent the areas of increasing astigmatism. (This contour plot is theoretical only and is not a representation of any existing lens.)

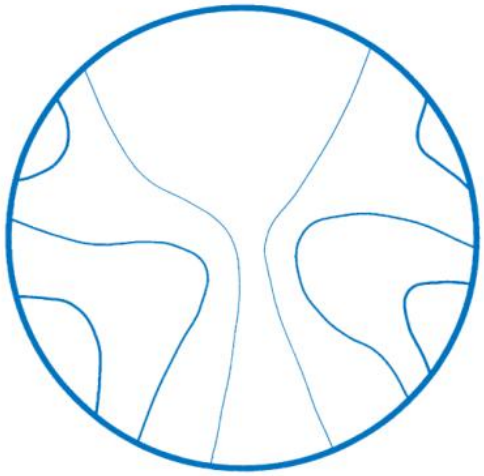

Figure 20.17 This progressive lens representation shows a lens with an aspheric upper front surface. Asphericity is allowed to continue into the upper half of the lens, with small amounts of astigmatism being evident in the periphery of the top half of the lens. (This contour plot is theoretical only and is not a representation of any existing lens.)

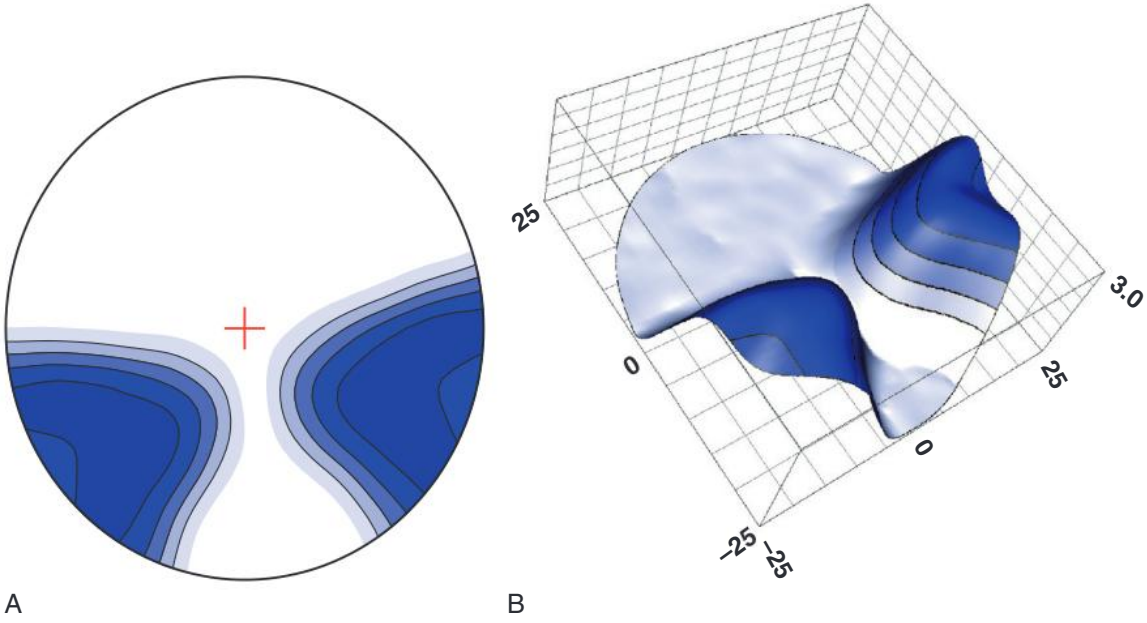

Figure 20.18 This is an example of a lens that has a somewhat hard progressive addition design. **A**, The contours of increasing astigmatism start at the border of the corridor and near zone. Each contoured area farther from the zone shows darker on the diagram and represents a change in measured cylinder power. The near portion is fairly wide, and the contour lines are closely spaced at the border of the progressive and near zones. This indicates a more rapidly changing cylinder power. **B**, This three-dimensional rendition of the same lens shows increasing cylinder as seen by increasing elevation. The lens is a 50- mm round lens. (Courtesy Darryl Meister, Carl Zeiss Vision.)

cylinder is concentrated. Distortions caused by more rapid power change may mean a slightly longer period of adaptation. Straight lines may appear more curved when viewed through the lower half of the lens than they do with other designs. (It should be noted that all progressive add lens designs cause this effect to some extent, at least during initial adaptation. Even the near portion of a bifocal lens can cause a straight line to appear curved.) The intermediate zone of a hard lens design is small and does not provide much horizontal or vertical viewing area.

Soft Designs

A soft design is one in which the change from the near zone to the peripheral area is gradual when compared with a hard design (Figure 20.19). As the wearer's eye begins to leave the near zone laterally, the amount of unwanted cylinder increases, but more gradually. From the wearer's point of view, it is not easy to determine where the near zone ends. A soft design has a slower vertical change in power as the wearer looks from distance to near. In other words, the progressive channel is longer and usually wider. This means that the wearer has

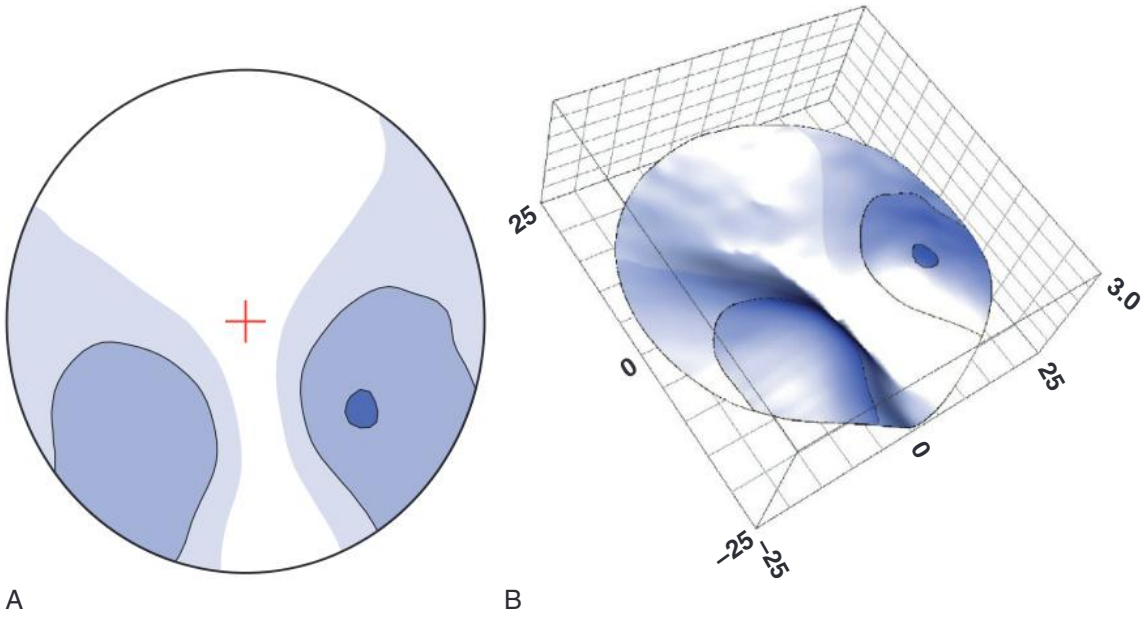

Figure 20.19 **A**, Here is an example of a soft progressive lens design. The near zone appears narrow, but the intervals of astigmatic increase are farther apart, indicating a more gradual increase in cylinder power. **B**, This three-dimensional perspective of the same lens shows how a softer design usually results in a smaller dioptric maximum amount of cylinder power spread over a wider area of the lens. (Courtesy Darryl Meister, Carl Zeiss Vision.)

to drop the eyes farther down into the lower areas of the lens before reaching the full near power.

The advantages of a soft design are easier, more rapid adaptation times, less distortion of peripherally viewed objects, and less "swim" of objects with head movement. Soft designs typically start with a smaller near zone and allow aberrations to spread over a larger area, including parts of the upper half of the lens. This means that the dioptric power of the unwanted cylinder will not be as large.

The disadvantages of soft designs include the possibility of a slight reduction in visual clarity in the upper peripheral areas of the distance lens, the necessity of dropping the eyes farther to reach the full add power and a "smaller" near zone. (To counter the problem of dropping the eyes farther to reach the full add power, the designer may increase the power progression so that approximately 85% of the add power is reached earlier. This is because most wearers can still function well with only 85% of the add power.) It is important to note that wearers do not always find the near zone of a soft design to be functionally as small as it may appear on an astigmatic contour plot. Because the amount of unwanted cylinder increases gradually as the eyes leave the near zone laterally, the wearer may be able to use the outer limits of the near area anyway, even when these areas contain a certain amount of unwanted cylinder power. For a summary comparing hard and soft designs, see Box 20.3.

BOX 20.3 Differences Between Hard and Soft Progressive Add Lens Designs

Hard Designs	Soft Designs
Shorter distance down to near-viewing area	Longer distance down to the near-viewing area
Wider areas of stable optics in both distance and near	
Narrower intermediate	Wider intermediate
Longer adaptation	Shorter adaptation
Some apparent curving of straight lines	Less apparent curving of straight lines
Highest dioptric value of peripheral distortion is greater than with soft designs	Highest dioptric value of peripheral distortion is generally less than with hard designs

Monodesigns Lead to Multidesigns

There are a multitude of ways to design a progressive addition lens. It is the job of the designer to anticipate the needs of the wearer. Initially, all progressives had a single design for all powers. This was later called a *monodesign*. A monodesign is limited in its effectiveness.

When a person first enters the age of presbyopia, the power of the needed near addition is low. This means that a new presbyope still has a considerable amount of accommodation left. For example, an individual with a +1.00 D add power really does not need a special correction for intermediate distances. If presbyopes with a +1.00 D add needed a special correction for intermediate viewing, there would be people wearing trifocal lenses with a +1.00 D add. Yet trifocal lenses are not made for add powers below +1.50 D.

With this in mind, designers began to ask whether or not consideration should be given to using more than one design for the same progressive lens, depending on the power of the near addition for that lens.

If changing add power is a major factor that alters the design needs for a progressive add lens, it would be logical to design a different lens for each add power. This is the basis for the *multidesign* lens, which varies to allow for changing needs with changing add powers.

Progressive Lenses Should Be Uniquely Right and Left Specific

From a historical perspective, when progressives were first emerging, it was not unusual for both left and right lens blanks to be identical. There was no difference between a right and left lens blank. Since the eyes turn inward for reading, the progressive corridor must tilt inward. Each lens was rotated so that the channels tilted nasalward.

This was not the best design because, when the lenses are rotated, prismatic effects are different for left and right eyes in certain directions of gaze. For example, if both eyes looked into the lower right areas of their respective lenses, those two locations were not the same in power and prismatic effect.

Right- and left-specific lenses should be designed to work as a pair so that peripheral power, cylinder, and vertical prism are matched for binocular viewing.

NEW MANUFACTURING METHODS ALLOW NEW LENS DESIGNS

There have been major changes in the way lenses can be manufactured. These changes employ a method of generating the lens surface that differs from what had traditionally been done. It is now possible to individually shape a lens surface to a unique form, having a varying surface curvature, then polish that surface to optical quality. This type of manufacturing is commonly referred to as either *free-form* or *digital surfacing*.

Here are some examples of what these changes in manufacturing mean in terms of possibilities for progressive lenses using free-form surfacing. Some possibilities may be used by one design, some by another.

- Conventional progressive addition lenses are normally made as semifinished lenses with fixed base curves. These semifinished lenses have the base curve and progressive add optics on the front. The power is then surfaced on the back in the laboratory. With free-form generating, the front surface can be custom surfaced to any base curve and the progressive optics included during surfacing. Then, the back surface is generated at the completion of the front surface. This way the base curve can be more closely matched to the power of the lens.
- The back surface of a conventional, semifinished progressive lens can be made as an aspheric or an atoric surface. Atoric curves can reduce the peripheral aberration called *oblique astigmatism* (see Chapter 18). This is especially important for progressive addition lens wearers who have a cylinder correction. When uncorrected oblique astigmatism is present, it combines with the peripheral distortion inherent in progressive addition lenses and can further degrade peripheral vision. An atoric design can improve peripheral vision.
- If a frame is fit with a specific vertex distance, the prescribed power of the lens can be altered for the vertex distance of the frame. These power changes are not limited to quarter diopter increments. The smoothing (fining) and polishing process no longer uses power-specific tools to bring the surface to optical quality.
- When a lens is tilted, there is a change in the sphere power, and a cylinder is induced whose axis is in the meridian of rotation (see Chapter 18). This power change can be compensated for on an individual basis, whether the tilt is pantoscopic tilt or face form. Again, the compensation may be done more exactly because it is not limited to quarter diopter increments.
- With free-form surfacing, it is possible to custom-make a progressive lens with the progressive power on the front of the lens, the back of the lens, or on both the front and the back of the lens.
- With free-form surfacing, the progressive zone of a lens can be shortened or lengthened to match the vertical depth of the frame and the vertical height of the wearer's eyes.

DESIGNS USING ASPHERIC/ATORIC LENS SURFACING METHODS

Lens quality is limited by how well lens aberrations can be corrected. In Chapter 18 the basics of spectacle lens design are explained. One of the limiting factors has been the inability to simultaneously correct oblique astigmatism in both major meridians for lenses with cylinder power. Oblique astigmatism could be corrected for spherical lenses by using a specific base curve or by using an aspheric surface. But if the lens had two different powers, as it does when prescribed cylinder power is present, then oblique astigmatism can only be corrected for both meridians at once if an atoric lens design is used. Atoric lenses are easier to make for single-vision lenses because they can be molded at the factory. But atoric lenses could previously not be made for a segmented multifocal or progressive lens because these lenses were surfaced for the correct power in the optical laboratory. Using conventional (nonfree-form) surfacing methods, the laboratory could only surface a spherical or a toric surface, not an atoric surface.

Using free-form surfacing, it is now feasible to custom generate and polish an aspheric or atoric surface in the optical laboratory. This makes it possible to correct more of the oblique astigmatism present in any spectacle lens, not just progressive lenses.

Progressive lenses have unwanted cylinder in the periphery of the lens simply because they are progressive lenses. Oblique astigmatism caused by lens aberrations will combine with this induced cylinder inherent in progressive addition lenses and degrade peripheral vision even more. If oblique astigmatism can be reduced, peripheral vision will improve.

One of the first types of progressives to include aspheric/atoric surfacing methods was the so-called *position-of-wear* or *as-worn* progressive lens design.

POSITION-OF-WEAR OR AS-WORN LENS DESIGNS

A major change in progressive lenses that took place because of free-form generating resulted in lenses sometimes referred to as *position-of-wear* or *as-worn* designs. These lenses include all the following factors in the design of the lens on an individual basis:

- Vertex distance
- Pantoscopic tilt
- Frame face form angle (wrap-around)
- An aspheric or atoric surface to optimize correction of lens aberrations.

The practitioner specifies the sphere, cylinder, and axis measures along with vertex distance, pantoscopic tilt, and frame face form. When the prescription is received, an optimum base curve is chosen for the front surface of the lenses, and the prescription is modified to allow for tilt, face form, and vertex distance (Figures 20.20 and 20.21.) Then, the amount of asphericity needed in each major meridian back surface is calculated. When the lenses are returned, the accompanying order information will include the sphere, cylinder, axis, and add power as originally ordered. It will also include new sphere, cylinder, axis, and add powers based on the calculated changes. For example, a lens may be ordered with powers of

$$+2.25 - 1.25 \times 027 \text{ add} + 2.25$$

The order may be returned with powers listed as

$$+2.21 - 1.22 \times 025 \text{ add} + 2.07$$

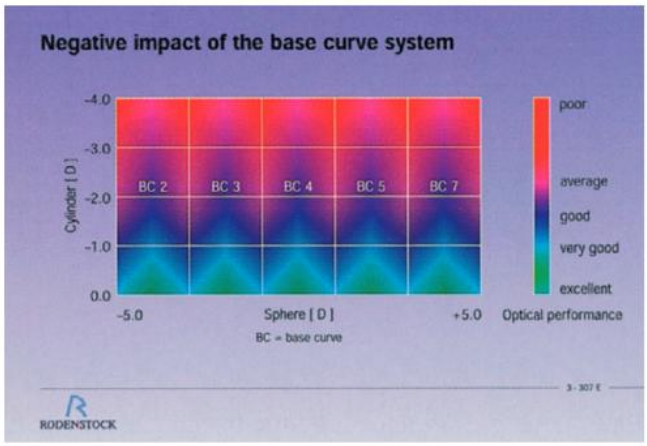

Figure 20.20 When a lens is made from semifinished blanks that come in certain finite intervals, the optical quality varies depending on how close that base curve comes to the ideal. However, even the ideal base curve does not deliver ideal optics when the lens has a high amount of cylinder. This figure shows conceptually how an ideal base curve, made with spherically curved surfaces, cannot be ideal for two different powers at the same time. It is not meant to show actual measures of vision or visual acuity. (From Baumbach P. Rodenstock Multigressiv—a technical prospective, Rodenstock, RM98052, p. 3, Figure 4.)

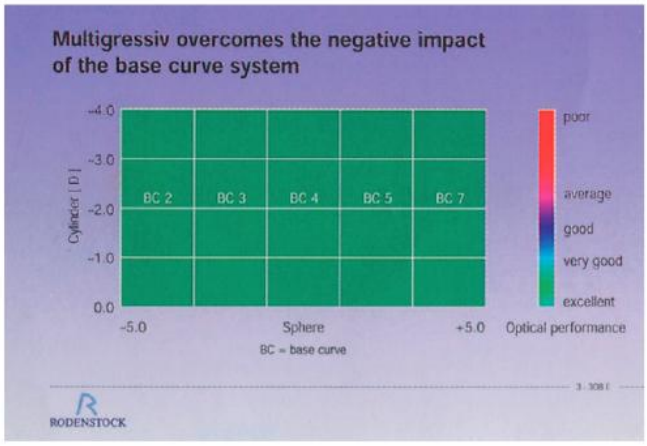

Figure 20.21 This figure shows conceptually what can happen to optical quality when optics can be corrected for base curve in both meridians of a lens surface at once when a prescription has cylinder power. This is done using an atoric surface custom cut for the prescription. The illustration is not meant to show any actual measures of vision or visual acuity. (From Baumbach P: Rodenstock Multigressiv—a technical prospective, Rodenstock, RM98052, p. 7, Figure 15.)

The second set of powers is what the lens actually will be as measured by a lensmeter. When worn in the expected position of wear, the wearer will experience the power intended in the original ordered power.

Even if vertex distance, pantoscopic tilt, and face form angle were not specified for these types of lenses, the lenses still have advantages because base curves can be optimized by varying the amount of asphericity on the surface of the lens.

Measuring for Position-of-Wear Lenses

In addition to the regular measurements taken for normal progressive addition lenses, position-of-wear progressive lenses perform better when additional measurements are taken. These measurements are vertex distance, wrap angle, and pantoscopic tilt. If these measurements are not taken, the lab will use default measurements. The lens may still perform well but not as well as when wearer-specific measures are used. (After all, these lenses are intended to be position-of-wear specific.)

Vertex distance is the distance from the back of the lens to the front of the eye. There are several ways vertex distance may be measured. The most basic would be to use a PD ruler. Viewing from the side with the already-adjusted frame being worn, the distance from the back of the lens to the front of the eye is measured with the ruler positioned at the side of the head. This measurement method is the least reliable. Besides being difficult to see, it is easy to be out of alignment, causing a parallax error.

The second method uses an instrument called a *distometer*. The distometer was described in Chapter 5 in the section on *Vertex Distance*. It is seen in Figure 5.12 and is shown in use in Figure 5.13.

The third method uses an iPad or other type of tablet device equipped with an application for taking spectacle-lens–related facial measurements. The tablet and application may be purchased from a specific lens manufacturer that is intended for use with their lenses or as an instrument to be used generally. Such tablets will take measurements for either progressive addition or other types of lenses.

Wrap angle (face form) may be measured with a tablet device or with a template. Wrap angle may be referred to as wrap-around or face form and is the number of degrees one lens (not both together) deviates from a straight line when viewed from above. When measuring the wrap angle, the measuring line starts at the center of the bridge and goes through both nasal and temporal lens edges.

Pantoscopic angle or pantoscopic tilt. When speaking of frame standard alignment, the pantoscopic angle is the angle the frame front deviates from the vertical when the glasses are held with the temples horizontal. However, when the glasses are being worn, the pantoscopic angle is the angle formed between the frontal plane of the face and the plane of the frame front. For many individuals these are the same. But when the wearer's ears are located higher or lower than expected, the temples of the frame are no longer horizontal but are angled upward or downward. This changes the as-worn pantoscopic angle. This pantoscopic angle measurement can be done manually with a protractor or a protractor-like device. Although such a method can produce viable results, a more reliable method is to use an iPad or tablet device.

ATORIC PROGRESSIVE LENSES

A progressive lens does not have to be a position-of-wear lens to incorporate atoric optics into the lens. Using atoric optics can be a large advantage, particularly for lenses with prescribed cylinder. Each lens may still be more exactly corrected for aberrations and individualized for prescription powers. The lenses are custom surfaced using free-form generating techniques.

LENS PAIRS DESIGNED WITH BINOCULARITY IN MIND

Considering right and left lenses as a pair at the time of manufacture is not a new concept. The most obvious example is the choice of base curves. Traditionally, when right and left lens powers are within two diopters of each other, the same base curve is chosen for both lenses. When powers are farther apart, two different base curves might be chosen. (For a more complete explanation, see Chapter 18, *Lens Design*, in the section *Appropriate Base Curves.*)

Recognizing how both eyes function together, lens designers have made strong efforts to make it easier for progressive addition spectacle

lens wearers to experience binocularity unhindered by the optics of those spectacle lenses. Early on, manufacturers recognized the binocular problems caused by just rotating the same design lens blank for use as either a right or a left lens. Since then, efforts have been made to balance prismatic effects between the eyes, even though most of those efforts were initially done under the assumption that both lenses would be very close in power to each other.

As many of those challenges were overcome, manufacturers have looked toward improving the ability of both eyes to work together better, unhindered by optics inadvertently induced by the spectacle lenses themselves. Here are some of the efforts made to improve binocularity. What follows may or may not be available, depending on the lens manufacturer.

If the power of one lens is different from the other, the prismatic effects at points of equal distances from the optical center of each lens will be different.

Vertical differences.[12] When anisometropia is present and the two eyes look down their respective progressive corridors, one eye will be further down the corridor than the other. This is because of differences in prismatic effects caused by the distance powers. A lens designer may choose to vary the corridor length of one or both of the two lenses. This is because of unequal powers; as the eyes look downward, one eye will be ahead of the other. The add powers are adjusted in the two corridors so they will match as the eyes move downward.

Horizontal differences.[12] When each lens has a difference in power, there is also a difference in how much the eyes need to turn inward (convergence) or outward (divergence) to see an object for distance or near viewing. This, too, is because of different distance lens refractive powers causing different prismatic effects. The designer may attempt to keep the eyes from having to diverge, since turning the eyes outward is noticeably more difficult than converging.

Magnification differences.[12] Plus lenses magnify, and minus lenses minify. The higher the lens powers, the larger (for plus) or smaller (for minus) the images through the lenses appear to be. This means that any time there are differences in lens powers between right and left lenses, there are also differences in the sizes of the images as seen by the right and left eyes. These differences may be reduced by making changes in base curves and lens thicknesses. A progressive addition design may give attention to corresponding areas of the lens pair in an attempt to selectively minimize magnification differences.

Creating similar optical aberration distributions.[13] Optical aberrations are inevitable in spectacle lenses and are made more challenging with progressive lenses. Creating a progressive addition lens pair that attempts to equalize the amount of aberration, and thus the retinal blur, between right and left eyes helps to increase binocularity.

SECTION 3: SPECIALTY PROGRESSIVE-STYLE LENSES

For years, bifocal and trifocal lenses were worn by the majority of presbyopic spectacle lens wearers. Yet they were not able to satisfy all the visual needs for every wearing situation. As a result, a number of segmented specialty lenses were developed.

Even though progressive lenses are clearly overtaking segmented multifocal lenses, it is also unrealistic to think that general purpose progressive lenses are able to fulfill everyone's specialized needs any more than segmented lenses could. If a progressive lens is truly for specialized tasks and will not be used for full-time wear, the lens may be called an *occupational progressive lens* and would be abbreviated *OPL*. Progressive addition lenses as a general category are often abbreviated as *PALs*.

SHORT CORRIDOR PROGRESSIVE LENSES

The *short corridor* category of specialty progressive lenses is really a subcategory of general purpose progressive lenses. The thing that makes this lens unique is that it is designed to allow a progressive addition lens to be worn in a frame with a small vertical dimension. Regular progressive lens corridors may be too long for such frames. Too much of the near portion of a regular progressive lens is cut off when the lens is edged for frames with narrow B dimensions.

The short corridor progressive has a faster transition between the distance and near portions of the lens. This means that the wearer gets quickly in to the near vision viewing portion when looking downward. Because the transition is short, the near vision viewing area is suitable, yet it is only logical that there will be some sacrifice of the otherwise larger intermediate portion.

Because these lenses have short corridors, not only does the vertical portion of the corridor have less intermediate vision, but the horizontal width of the intermediate viewing area is considerably narrower. In simplified terms, the short corridor progressive lens has a hard instead of a soft design. The advantage is that the near viewing area will be wider. Some eye care practitioners will intentionally place a short corridor progressive lens into a frame with a larger vertical dimension in order to provide the wearer with a wider near zone than would otherwise be possible using a standard progressive lens.

While most standard progressive lenses have minimum fitting heights of 18 mm or greater, short corridor progressive lenses have minimum fitting heights of 17 mm or less, generally ranging from 14 to 17 mm. When choosing a short corridor progressive lens, be certain that the minimum fitting height is suitable for the frame. Even short corridor progressive lenses can come up short on near viewing if the frame has an exceedingly narrow vertical depth.

Short corridor progressive lenses are fitted in the same manner as regular progressive lenses. Monocular PDs are needed, and the fitting cross is placed in the center of the pupil.

Keep in mind that many higher end position-of-wear and personalized progressive lenses will match corridor length to the frame. In other words, if a higher end progressive lens is chosen, the lens corridor length will then be custom sized to appropriately match the vertical depth of the frame selected.

ASSISTIVE POWER LENSES

Even before the time when individuals would normally move into segmented multifocal lenses or progressive addition lenses, those who must use their eyes for long periods of near viewing often experience visual fatigue. When segmented multifocal lenses were the only option available, bifocal lenses were not typically available in add powers below +1.00 D. Who would want to put up with the visible segment when it wasn't absolutely necessary? Besides having to get used to the line, it carried the stigma of increasing age. But what about progressive addition lenses?

As seen earlier, a progressive addition lens with a low add power can be made with extremely low amounts of unwanted peripheral cylinder. Even when expanding to a large near viewing area, power changes can be made almost imperceptible to the wearer and are not detectable to others. Still, if a low-power progressive lens is offered to most people younger than the age of those developing presbyopia as a progressive addition lens what happens? People know what a progressive addition lens means and often have an avoidance reaction.

The design of such a lens is different enough from a traditional progressive lens that calling it by a different name is justifiable. There is an increased need for a lens that has a small amount of "assistive" power

for near tasks. Most everyone now spends increasing amounts of screen time on computers, tablets, and smart phones. This includes students, those who would otherwise be a long way off from needing a typical presbyopic prescription, as well as pre-presbyopes. By recognizing the differences in design and adopting a name that more accurately describes the function of the lens, eye care providers are able to help a great number of people for whom such a lens is especially well suited.

What Does the Lens Look Like Optically?

From an optical standpoint, the lens has an upper portion with single-vision optics that are basically undisturbed. The lower portion of the lens is normally described as giving a "boost" in power and, although invisible, resembles the top of a very large round segment lens (see Figure 20.22). Even though it may appear as if it could be a large segment blended bifocal lens, it is not. Power change is gradual.

How Are Lens-Fitting Measurements Taken?

The only measurements needed are to locate the centers of the pupils. With the frame adjusted as it will be worn, measure the monocular PDs and pupil center heights. This will position the "boost" zones where they need to be.

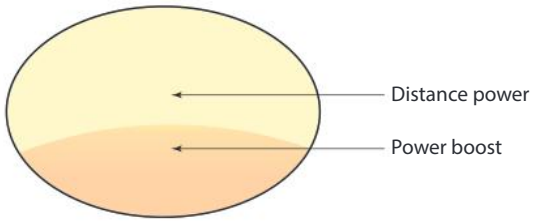

Figure 20.22 An Assistive Power lens adds a relatively small amount of plus power in the lower portion of the lens, giving a boost in plus power when viewing near tasks. This boost may range in power anywhere from approximately +0.40 D for students and young professionals up to +1.32 D for pre- or beginning presbyopes. Exact powers available depend upon the manufacturer.

What Types of Power Boosts Are Available?

Power boosts normally start at about +0.50 D and may have one or two additional higher powers available, depending on the manufacturer.

DEGRESSIVE POWER LENSES

Degressive power lenses started out as a replacement for single-vision reading glasses. This lens also goes by other names, including *near variable focus lenses,* or simply *OPLs* (occupational progressive lenses). Over time the lens has become the lens of choice for someone working with digital screens in a small office where intermediate and near vision are the primary viewing needs.

The lenses are called *degressive power lenses* because the starting point for lens power is really the total near power used when working at the reading distance. Beginning from this point, lens power *degresses* or decreases in plus power in gradual amounts as the eye looks higher up in the lens. The power at the top of the lens may never end up with the full distance power of the prescription.

To get an idea of how the lenses are constructed, take the example of a prescription for a presbyopic emmetrope who has no needed power for distance and a +2.00 D add for reading at 40 cm. The normal progressive addition lens would have powers as shown in Figure 20.23 with no power in the upper (distance) portion. Power gradually increases until it reaches the prescribed +2.00 D add power in the lower near portion.

This lens construction is not the case with most degressive power lenses. The farthest distance that some people who work in small office environments need to see clearly might be equal to the distance of someone sitting across the desk from them. They need a clear view of a computer monitor placed at an intermediate viewing distance and a clear view of the customary 40-cm near-working distance for reading.

If we were to need a +1.00 D power in the upper portion of the lens, we can gradually increase plus power until a total of +2.00 D is achieved for near viewing. This would appear as shown in Figure 20.24. Note that the progressive zone for this type of lens is longer and wider than the

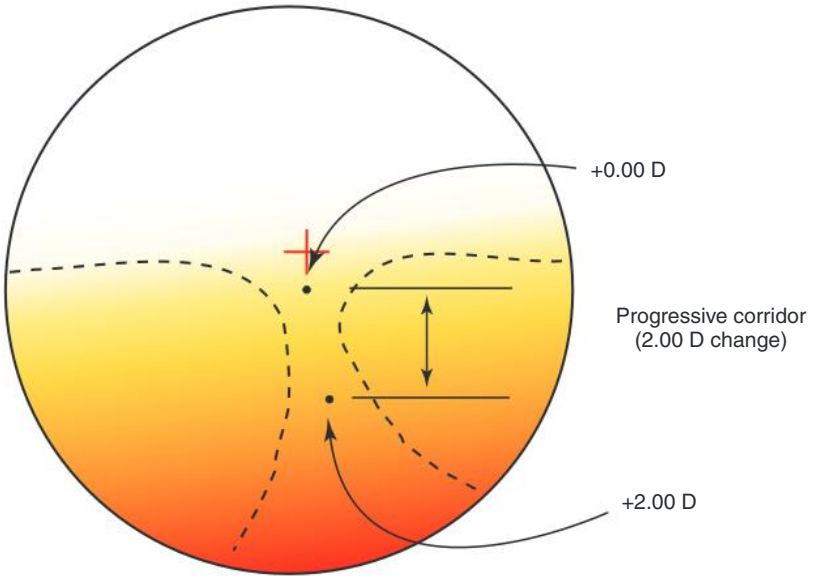

Figure 20.23 This is a simplified drawing of the structure of a progressive addition lens with a plano distance prescription and a +2.00 D add. The "power range" of this lens is a full 2 D.

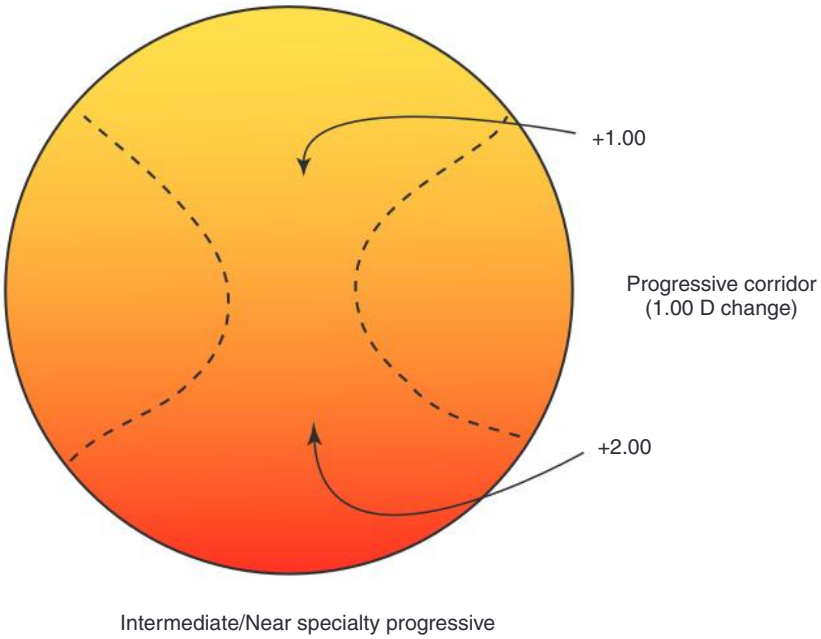

Figure 20.24 When a prescription with plano distance power and a +2.00 D add is placed in a degressive power lens having a 1.00 D power range, the power difference between upper and lower portions is much less. The progressive zone is also lengthened. This makes the progressive zone wider and reduces the intensity of peripheral distortion. This simplified drawing of the lens structure, based on the same prescription, can be compared with the standard progressive lens in Figure 20.23.

normal progressive corridor found in a general wear progressive lens. This works well, and for this type of working environment these lenses give excellent intermediate and near vision with less peripheral distortion. Here is why:

- A longer progressive zone will result in less peripheral distortion.
- In a degressive power lens, the difference between the powers in the upper and lower halves of the lens are usually smaller. In the example, instead of having a difference of +2.00 D, this lens has a difference of only +1.00 D. In reality, this is a +1.00 D add instead of a +2.00 D add. The smaller the add power, the smaller the amount of unwanted cylinder will be.
- When wearing a degressive or near variable focus lens, more visual work will be done using mid-level and downward viewing than with a standard progressive lens in which clear distance vision is important. The designer has the option of moving a larger proportion of the peripheral distortion inherent in progressive lenses into the upper periphery of the lens.[11] Increasing the area of distortion decreases its intensity.

Power Ranges

With general purpose progressive lenses, we think of beginning with the distance power in the upper portion and increasing plus power as we go downward. With degressive power lenses, we begin with the near power. The reference power is the near power instead of the distance power. We start with the near power in the lower portion and decrease plus power moving up to the distance portion. This is no longer an addition, but a decrease in power or *degression*.[11] Manufacturers call this amount of degression the *power range* of the lens.

This means that degressive lenses do not come in regular add powers like general purpose progressive lenses. They instead come with one or more power ranges. To repeat, the *power range* is the difference in power between the lower and upper areas of the degressive power lens.

Example 20.2

Suppose a degressive power lens made by a certain manufacturer comes in only one power range and that power range is 1.00 D. This means that there will always be a 1.00 D difference (degression) between the lower and upper portions of the lens. If a person has a regular prescription intended for distance and near vision with powers of

$$\begin{aligned} \text{R}&: \text{ plano} \\ \text{L}&: +0.25 - 0.50 \times 180 \\ \text{Add}&: +2.25\,\text{D} \end{aligned}$$

what powers would be found in the lower and upper areas of the lenses for this manufacturer's degressive power lens?

Solution

When trying to anticipate the powers in a degressive power lens, begin with the total near power. Total near power is the sum of the distance power and the near add.

For the right lens this power is

$$\begin{aligned} &\text{(Distance power)} \\ &+\text{(Add power)} \\ &= \text{(Total near power)} \end{aligned}$$

or

$$\begin{aligned} &0.00 \\ &+2.25 \\ &= +2.25 \end{aligned}$$

Since the lens has a power range, or degression, of 1.00 D, the upper area of the lens will have 1.00 D less plus power than the lower area of the lens. So the upper area of the lens has a power of

$$\begin{array}{l}(\textit{Total near power})\\ -(\text{degression})\\ \hline =(\textit{Upper power of the lens})\end{array}$$

or

$$\begin{array}{r}+2.25\\ -1.00\\ \hline =+1.25\end{array}$$

In a lensmeter, the upper portion of the lens reads +1.25 D, and the near portion reads +2.25 D.

For the left lens, the total near power is

$$\begin{array}{l}(\textit{Distance power})\\ +(\textit{Add power})\\ \hline =(\textit{Total near power})\end{array}$$

or

$$\begin{array}{r}+0.25-0.50\times 180\\ +2.25\\ \hline =+2.50-0.50\times 180\end{array}$$

So the upper area of the lens has a power of

$$\begin{array}{r}+2.50-0.50\times 180\\ -1.00\\ \hline =+1.50-0.50\times 180\end{array}$$

Degressive Power Lenses Differ

Degressive power lenses are made by many different manufacturers. They are not all the same. Each has its own characteristic set of power ranges intended for different tasks and should not be expected to perform in the same way that another manufacturer's might.

Example 20.3

A wearer has a normally written prescription for distance and near vision of

$$\begin{array}{c}+0.75-0.75\times 175\\ +0.75-0.75\times 005\\ \text{Add}+2.50\,\text{D}\end{array}$$

However, the wearer works in a small office environment and uses a computer a fair amount of the time. If a degressive power lens with a power range of 1.50 D is chosen, what powers will be found in the lower portion and upper portion of the right lens?

Solution

With a degressive power lens, it is easiest to begin with the near power first, then find the power in the top part of the lens. The near power will be found by adding the near addition to the prescribed distance power.

$$\begin{array}{r}+0.75-0.75\times 175\\ +2.50\\ \hline =+3.25-0.75\times 175\end{array}$$

A lens with a degression of 1.50 D shows a plus power decrease from the near power by the amount of the degression. The power in the upper portion of the lens is found by subtracting 1.50 D of power from the near power.

$$\begin{array}{l}(\textit{Total near power})\\ -(\textit{degression})\\ \hline =(\textit{Upper power of the lens})\end{array}$$

or

$$\begin{array}{r}+3.25-0.75\times 175\\ -1.50\\ \hline =+1.75-0.75\times 175\end{array}$$

The power in the upper portion of the lens will be $+1.75 - 0.75 \times 175$.

Power Changes in the Vertical Meridian

The greater the amount of power degression a lens has, the more the contour plot of the lens will resemble that of a general purpose progressive lens. Figure 20.25 shows a simplified representation of a lens with a small degression compared with a lens having a larger degression. Higher degressions result in narrower progressive zones and greater amounts of unwanted peripheral astigmatism. Yet even with higher amounts of degression, because of its increased corridor length, the progressive viewing zone will be considerably wider than that of a standard progressive lens. (An important note: *Do not* attempt to create a special purpose progressive lens by modifying the powers of a general purpose progressive lens. Results are not at all like when using a segmented bifocal lens with intermediate power in the upper area and near power through the segment. The end result will be much inferior to that of an appropriately chosen degressive power lens.)

Using First Principles for Matching a Degressive Power Lens to the Needs of the Wearer

When someone has two specific distances at which they do most of their work, the eye care practitioner may decide to target those distances. In this case the type of lens should be chosen with a power range appropriate for the prescription. Here is how it is done.

Example 20.4

Suppose a person has a regular prescription of

$$\begin{array}{c}\text{R}:+1.25-0.50\times 090\\ \text{L}:+1.25-0.50\times 090\\ +2.25\,\text{D Add}\end{array}$$

This person does most of her near work at the conventional 40-cm working distance but uses a computer screen situated at an intermediate distance. The examiner tests for the best refractive correction for this computer screen distance. This distance is found to have an intermediate add power of +1.25. If a degressive power lens is to be used:

A. What would the prescription read in the lensmeter through the upper and lower portions of the appropriate near variable focus lens? (Assume that the power of the upper portion and mid-portion of the lens will be the same.)
B. What would the correct power range be?
C. When choosing from the lens types, a degressive-type lens would be chosen that would yield this power in the upper portion of the lens.

Solution

A. Through a lensmeter, the lower portion of this lens would have the regular near power of the prescription. This would be

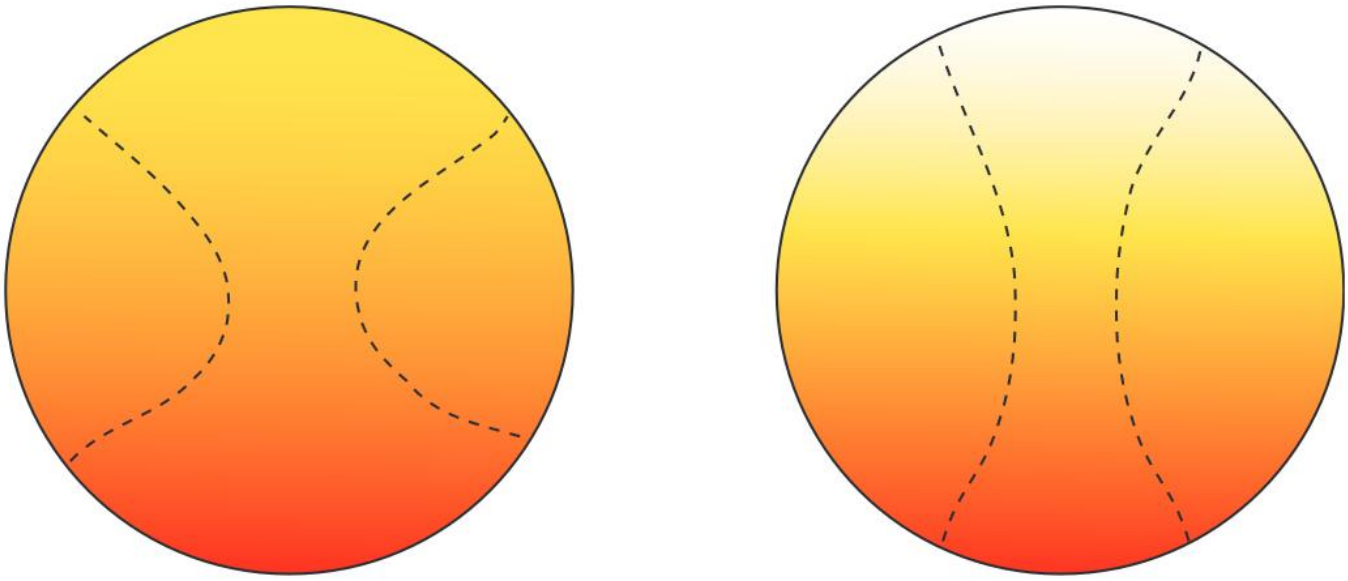

Figure 20.25 When a degressive power lens has a small power range, the zone of optimal vision will be larger. Here are two simplified drawings comparing how one lens with a small degression might compare with another lens having a larger degression. Which of the two would be the most appropriate lens will depend on the intermediate and/or near tasks for which the lens is intended. *OPL*, occupational progressive lens.

$$\begin{array}{r} +1.25 - 0.50 \times 090 \\ +2.25\ \text{Add} \\ \hline = +3.50 - 0.50 \times 090 \end{array}$$

In the top part of the lens, we want to have the correct intermediate power. This will be the sum of the distance power plus the intermediate add, which is

$$\begin{array}{r} +1.25 - 0.50 \times 090 \\ +1.25\ \text{Add} \\ \hline = +2.50 - 0.50 \times 090 \end{array}$$

B. The power range, or degression, is the power decrease between lower and upper parts of the lens—in other words, the power difference between intermediate and near powers. This can be found by taking the difference between $+2.50 - 0.50 \times 090$ and $+3.50 - 0.50 \times 090$, which is

$$\begin{array}{r} (+3.50 - 0.50 \times 090) \\ (+2.50 - 0.50 \times 090) \\ \hline = 1.00 \end{array}$$

Power range, or degression may also be found by taking the difference between the intermediate and near add powers, which would be

$$\begin{array}{r} (+2.25) \\ -(+1.25) \\ \hline = (+1.00) \end{array}$$

Both methods result in a power range of 1.00 D.

C. Next, a lens is found that has, or most closely matches, a power range of 1.00 D.

The example just given assumes that the occupational progressive lens is to be used with maximum viewing distance being the distance from the eyes to the computer screen. If the viewing distance is to go beyond the computer viewing distance, then a larger power degression might be chosen.

Simplifying the Choice

In an effort to simplify the choice of the correct degressive power lens, manufacturers are often specifying near variable focus lenses according to how they are to be used. The assumption is that the majority of these lenses will be used for office and/or computer work. Using these same lenses for other types of work performed at equivalent viewing distances will also be successful. Here are some examples of primary choices offered. Each manufacturer will have unique names for their own lenses.

Primarily for Shorter Working Distances

This would include reading, hand-held tablets or smart phones, and some computer use.

For use at near through intermediate ranges.

Here, the main concern would be to place more emphasis on the intermediate range of computer-monitor distances, yet still allow clear vision in a small office or cubicle out to a distance of about 7 feet or slightly over 2 meters.

For clear vision anywhere in a moderately-sized room.

In this case, one might expect to have clarity anywhere in the room but not in a hallway, in an auditorium, or outdoors.

For clear vision in an office, but with an area in the uppermost part of the lens for distance vision.

When reading through these choices, the logical question is why would anyone choose anything but the last one? To answer this question, proceed on to the next section.

Degressive Power Lenses That Include Distance Powers

This fourth and last example of a simplified choice for a degressive power lens type is one that will achieve clear vision in an office but contains an area in the uppermost part of the lens for distance vision.

This type of lens requires that the wearer drop the chin and look through the very top portion of the lens to see in the distance. Yet, since the lens is entirely an occupational lens, this is not necessarily a disadvantage and may be considered an expected trade-off for intermediate viewing enhancement.

The intermediate area of the lens is positioned in front of the eye as if looking through a trifocal segment straight ahead (Figure 20.26). Because the progressive zone is longer, going almost from the top to the bottom of the edged spectacle lens, the intermediate and near zones will still be considerably wider than standard progressive lenses, although not as wide as degressive power lenses with smaller power ranges. These lenses should not be used as a replacement for regular, full-time–wear progressive addition lenses.

Such lenses are still fit like regular progressive lenses but require enough vertical depth to the frame to keep from cutting off the needed top and bottom areas of the lens. They are certainly not feasible for frames with narrow B dimensions.

In all of the above choices, the practitioner may only be required to specify the distance prescription and the add power. The required degressive power is based on these numbers and on the type of lens chosen.

Fitting the Degressive Power Lens

Degressive power lens-fitting recommendations vary, depending on lens style. For example, some lens types may only require a binocular near PD but no fitting height, just like prescription single-vision lenses for reading. The reason it is possible to use a binocular PD instead of a monocular PD is because the progressive zone of the lens is much wider than in standard progressive lenses.

In contrast, most office-type lenses are fit like a standard progressive lens using monocular PDs and fitting cross heights measured to the center of the pupil. The distance prescription and standard near addition would be specified. If no power range is specifically requested, the laboratory will use a recommended range based on the degressive lens style chosen and the add power of the prescription.

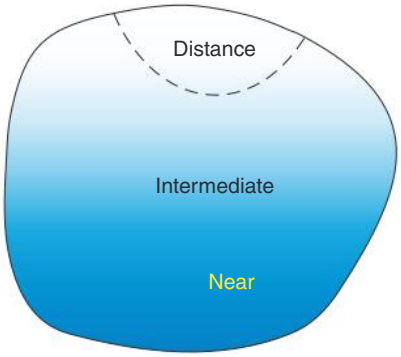

Figure 20.26 Here is a degressive power lens with a small, upper portion for distance vision. It shows a large functional intermediate zone with the small distance area in the upper portion of the lens. If the B dimension of the frame is too small, this distance portion can easily be cut off during the edging process.

SECTION 4: PRISM AND PROGRESSIVE LENSES

PRISM THINNING

Without the use of prism thinning, progressive addition lenses in certain power ranges would manifest increased thickness. This is especially evident when the distance powers are either plus or low minus. Without prism thinning, progressive lenses in plus or low minus powers will be thicker than flat-top multifocal lenses of equal power. This increased thickness is a result of the steepening front curve in the lower half of the progressive addition lens. (This same problem also occurs in "Executive" multifocal lenses and can be solved in the same way.) As the surface curvature steepens, the bottom lens edge thins. To keep the lower lens edge from becoming too thin, the whole lens thickness must be increased.

To overcome the problem, the lower edge must somehow be thickened without thickening the upper edge. This can be done by adding base-down prism to the whole lens. When this is done properly, overall lens thickness can be made to decrease. The technique, known as yoked base-down prism, is illustrated in Figure 20.27. Naturally, both right and left lenses must receive the same amount of base-down prism, otherwise the wearer will experience double vision as a result of unwanted vertical prism differences.

The exact amount of prism needed to thin the lens varies according to the strength of the addition, the size and shape of the lens after edging, and the design of the lens. As an early *rule of thumb*, Varilux suggested adding prism power amounting to approximately two-thirds of the power of the add. (The use of yoked base-down prism for Varilux lenses was referred to by the name Equithin, although this same thinning technique may be used for any progressive lens.)

Optical laboratories use prism thinning routinely without consulting the account. Prism thinning has a very positive effect on reducing lens thickness and weight for lenses in the appropriate power range. (Note: Although thinning is primarily base down, in some cases high minus lenses may be prism thinned using base-up prism. This would occur if the fitting cross of a minus lens were located high enough in the lens to result in a thicker bottom edge.[14])

According to a study by Sheedy and Parsons,[15] small amounts of yoked base-down prism are not disturbing to the wearer. Those tested could not differentiate between the absence of prism and 2Δ base down in both eyes. However, when prism was increased to 4Δ base down, there were significant postural changes by the wearer.

Prism Thinning Causes Prism at the PRP

It should be mentioned that base-down prism used to thin the lens will show up at the prism reference point (PRP) of the lens. This is particularly important to note when only one lens is to be replaced since both right and left lenses must have the same amount of vertical prism. Thus vertical prism found at the PRP of the lens is acceptable when both left and right lenses have the same amount of vertical prism.

THE EFFECT OF PRESCRIBED PRISM ON PROGRESSIVE LENS-FITTING

Success in fitting progressive addition lenses depends on accurate horizontal placement of the monocular PDs. If monocular PDs are incorrect, the eyes do not track down the progressive corridor. This reduces intermediate vision. Incorrect PDs also displace the reading zone, reducing its usable size.

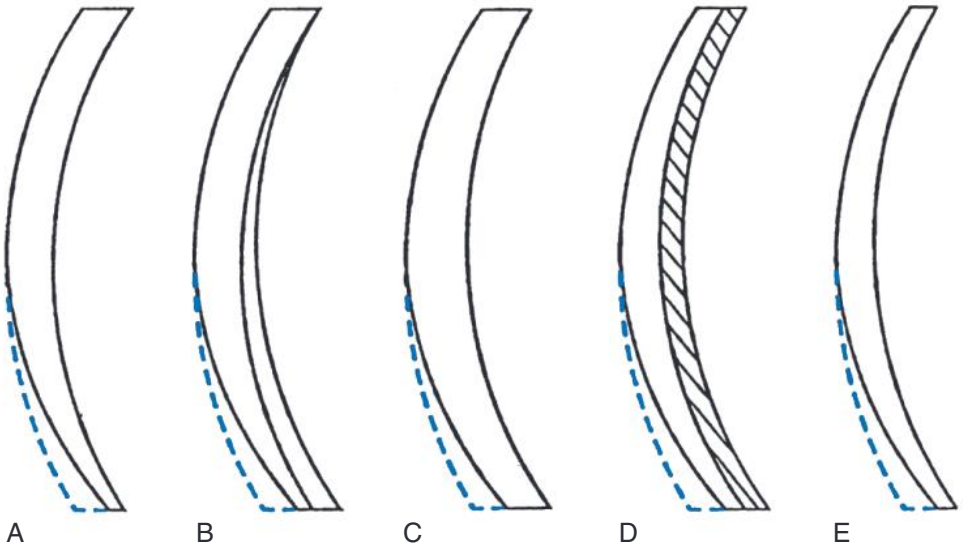

Figure 20.27 This figure shows the use of base-down prism to thin a progressive addition lens. **A**, Shows the progressive addition lens as would be ground without prism thinning. The dotted lines indicate how the lens would be curved if it were a single-vision lens instead of a progressive lens. **B**, Adding base-down prism thickens only the bottom of the lens, not the top. **C**, Here, the line between prism and original lens has been removed. It is now possible to see how this lens with newly-added base-down prism could be further thinned because both top and bottom are thick. **D**, The hatched area shows how much lens thickness may be removed now that both edges are equally thick. **E**, Excess lens thickness has been removed and progressive lens prism thinning achieved.

Success in fitting progressive addition lenses is also influenced by the accuracy of fitting cross heights. An inaccurate fitting, cross height will cause one eye to track down the corridor ahead of the other. This means that the add power is not increasing equally for the two eyes. The eye farther down one corridor is looking through more plus power than the partner eye following a few steps behind. An inaccurate fitting cross height also causes the eye to track down the progressive corridor off-center. This narrows the effective width of the intermediate viewing area.[16]

When prism is placed before the eye, it causes the image of an object to be displaced in the direction of the prism apex. The eye must turn toward the apex to view the displaced image. For example, if base-down prism is placed before one eye, that eye turns upward toward the apex to fixate the displaced image. (This concept was explained in Chapter 5 and is shown in Figure 5.27.)

Prescribed Vertical Prism Changes Fitting Cross (and Bifocal) Heights[17]

When vertical prism is present in a prescription, it causes one of the wearer's eyes to turn slightly up or down. But when fitting cross height measurements are taken, the prism is not present. When the wearer is able to keep the eyes working together without the prism, the eyes are looking straight ahead. One eye will not likely be turned upward or downward in relationship to the other. However, once the prescription lenses are in the frame, the eye must turn in the direction of the apex of its prescribed prism. The amount of displacement in the spectacle plane will be 0.3 mm for every 1Δ of prescribed prism.

When vertical prism is present, the fitting cross should be raised 0.3 mm for every diopter of base-down prism or lowered 0.3 mm for every diopter of base-up prism.

If the entire amount of vertical prism is prescribed before one eye, the vertical displacement of the fitting cross should be carried out on one lens. But if the vertical prism is split, the displacement of the fitting crosses also should be split in the same proportion.

To be certain of vertical fitting-cross positioning with prescribed prism, cover the wearer's left eye when measuring the fitting cross for the right eye. Then, when measuring fitting cross height for the left eye, cover the wearer's right eye.

Example 20.5

A prescription reads as follows:

R: $+2.75 - 1.00 \times 180$ 3Δ base up
L: $+2.75 - 1.00 \times 180$ 3Δ base down

The frame of choice is adjusted to fit as it should when being worn. Next, fitting cross heights are marked on the glazed lenses to correspond to pupil center location. Heights are measured to be as follows:

R: 27 mm
L: 27 mm

What fitting cross heights should be ordered?

Solution

Vertical prism for the right lens is noted. The amount of vertical compensation is calculated as follows:

Vertical prism amount × 0.3 = Change in fitting cross height in millimeters.

Or in this case,

$3 \times 0.3 = 0.9$ mm.

This is rounded off to 1 mm. Because prescribed prism causes the pupil of the right eye to be displaced 1 mm downward, the fitting cross must be moved 1 mm downward as well.

The left lens has an equal but opposite amount of vertical prism. Therefore the prism in the left lens necessitates

moving the left fitting cross 1 mm upward. The end result is that the two fitting cross heights are modified and should be ordered as:

R: 26 mm.
L: 28 mm.

Prescribed Horizontal Prism Changes PD Measurements

When horizontal prism is prescribed, failure to horizontally compensate the MRP placement will cause the eyes to track along the inside or outside edge of the progressive corridor. This greatly reduces the usefulness of the intermediate zone and narrows the field of view for near work.

Example 20.6

Suppose a prescription reads as follows:

R: $-2.25-0.50\times180$ 5Δ base in
L: $-2.25-0.50\times180$ 5Δ base in

Using a pupillometer, the monocular PDs are measured as follows:

R: 29.5 mm
L: 30.0 mm

What monocular PDs should be ordered to compensate for the prescribed horizontal prism?

Solution

Noting horizontal prism, the amount of pupil displacement is calculated as follows:

$$5\times0.3=1.5\text{ mm.}$$

Base-in prism will cause the eye to move outward by an amount equal to 0.3 mm for every diopter of horizontal prism. In this case, 5Δ of base-in prism will cause each pupil to be displaced outward by 1.5 mm. The resulting monocular PDs are modified to:

R: 31.0 mm.
L: 31.5 mm.

When Might the Amount of Horizontal Prism Be Modified?

When prism is prescribed in conventional, nonprogressive, multifocal lenses, the PD is not modified to allow for a change in pupil location. This is quite acceptable because the segment widths of segmented multifocal lenses are so wide in comparison with the corridors of progressive addition lenses that there is little need for modification.

When a prescriber tests for prism, the measuring prism on the phoropter is in front of the spherocylinder lens combination. As the measuring prism is increased in power, the eye responds by turning, leaving its location behind the optical center of the refractive lenses. When the eye moves away from the optical center of the lens combination, a second prismatic effect occurs. This is caused when the individual is no longer looking through the optical center of the refracting lens but through a decentered point on the lens. This induces a decentration-type of prismatic effect (Figure 20.28). Practically speaking, this second prismatic effect is of no consequence since the measuring prism in the phoropter is taking it into account. But what happens if the refractive MRP location is altered during fitting? When the fitting cross is changed to correspond to the prismatically altered eye position, the decentration prism that was present during refraction disappears. Remember that monocular PDs are typically measured without any lenses in front of the eyes. These PD measurements may even be taken using the proposed frame with only demo lenses. Without prescribed prism before the eyes causing the eyes to turn outward or inward, the net prismatic effect that was present during refraction has changed. When prescription sphere and cylinder powers are small, this is of minimal consequence. However, as refractive power increases, the prismatic effect on the eyes becomes evident.

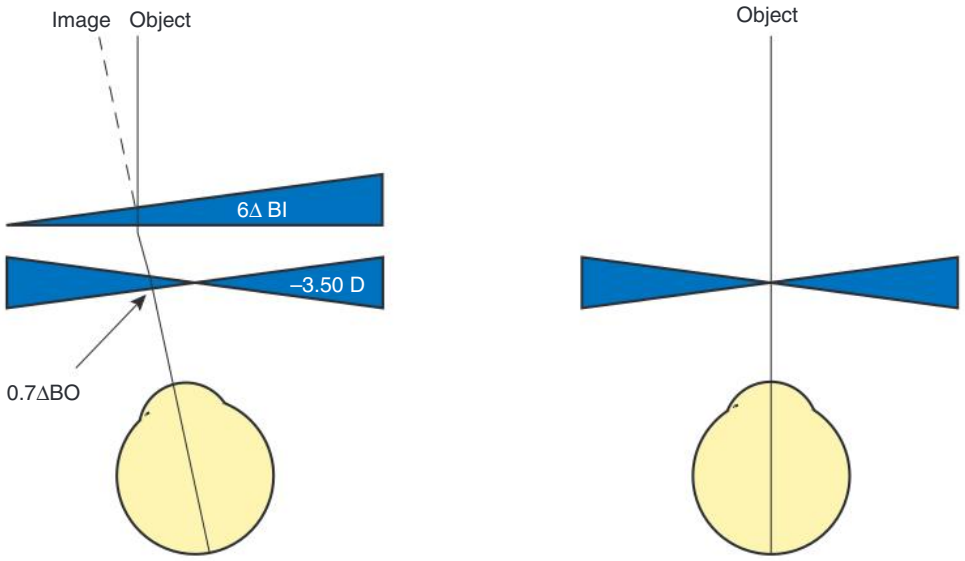

Figure 20.28 A measuring prism in front of the refractive lens will cause the eye to turn outward. As it turns, it leaves its previous location directly behind the optical center of the lens. *BI*, base in; *BO*, base out. (From Brooks CW, Riley HD. Effect of prescribed prism on monocular interpupillary distances and fitting heights for progressive add lenses. *Optom Vis Sci* 1994;71:403. Figure 4)

Example 20.7

Suppose a person is wearing or needs a prescription as follows:

R: −3.50 sphere.
L: −3.50 sphere with 6Δ base-in prism.
+2.25 Add.

(Although it may not be advisable to place all prism in front of one eye, we will use this example for simplicity.)

Before refraction, the monocular PDs are measured using a pupillometer. There are no refractive lenses in place. The PD measures as follows (Figure 20.29):

R monocular PD = 31 mm
L monocular PD = 31 mm

How should the monocular PDs and prescribed prism amounts be modified to allow the eyes to accurately track down the progressive corridor and still maintain the same net prismatic corrective effect?

Solution

Placing 6Δ of base-in prism before the left eye will cause the eye to deviate outward by:

$$6 \times 0.3 \text{ mm} = 1.8 \text{ mm},$$

which will be rounded off to 2 mm.

During phoria testing, the eye was looking 2 mm temporally through the −3.50 D refracting lens (see Figure 20.28). Using Prentice's rule, we see that prism caused by the eye being decentered in relation to the lens is:

$$\Delta = cF$$
$$= 0.2 \times 3.5$$
$$= 0.7\Delta$$

Since the lens is minus, prism caused by the eye moving in relationship to the refractive lens is base out. Therefore the net prismatic effect for the eye is:

$$(\text{Prescribed}\,\Delta) + (\text{Decentration}\,\Delta) = (\text{Total}\,\Delta).$$

Or in this case,

$$6\Delta \text{ base in} + 0.7\Delta \text{ base out} = 5.3\Delta \text{ base in}.$$

To position the progressive zone in front of the eye, the MRP must be moved 2 mm outward. (When the position of the MRP moves, so does the fitting cross location. The fitting cross is directly above the MRP.) When the MRP moves outward, the finished spectacle lens prescription will no longer duplicate the refractive situation. This is because the 0.7Δ of decentration prism caused by the −3.50 D lens no longer exists (Figure 20.30). To maintain the same total prismatic effect, the prescribed prism must be reduced from 6Δ base in to 5.3Δ base in (rounded to 5.25Δ base in).

The PDs are ordered as follows:

R monocular PD = 31 mm.
L monocular PD = 33 mm.

It is helpful to note that when the MRP is moved in the direction of eye deviation, there will always be a reduction of prescribed prism for minus lenses and an increase in the amount of prescribed prism for plus lenses. In other words:

- For minus lens: *reduce* the prescribed prism by an amount equal to the calculated decentration prism.
- For plus lenses: *increase* the prescribed prism by an amount equal to the calculated decentration prism.

When filling an existing prescription, it should be noted that a modification to the prescribed prism amount that is done to

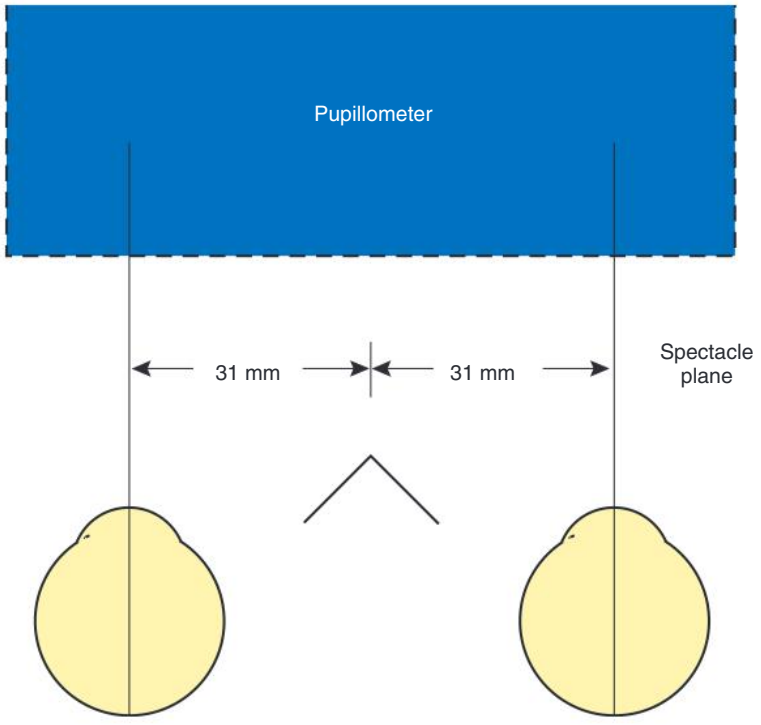

Figure 20.29 A pupillometer normally measures the interpupillary distance with no lens correction in place and with the eyes in a straight-ahead position. (From Brooks CW, Riley HD. Effect of prescribed prism on monocular interpupillary distances and fitting heights for progressive add lenses. *Optom Vis Sci* 1994;71:403. Figure 5.)

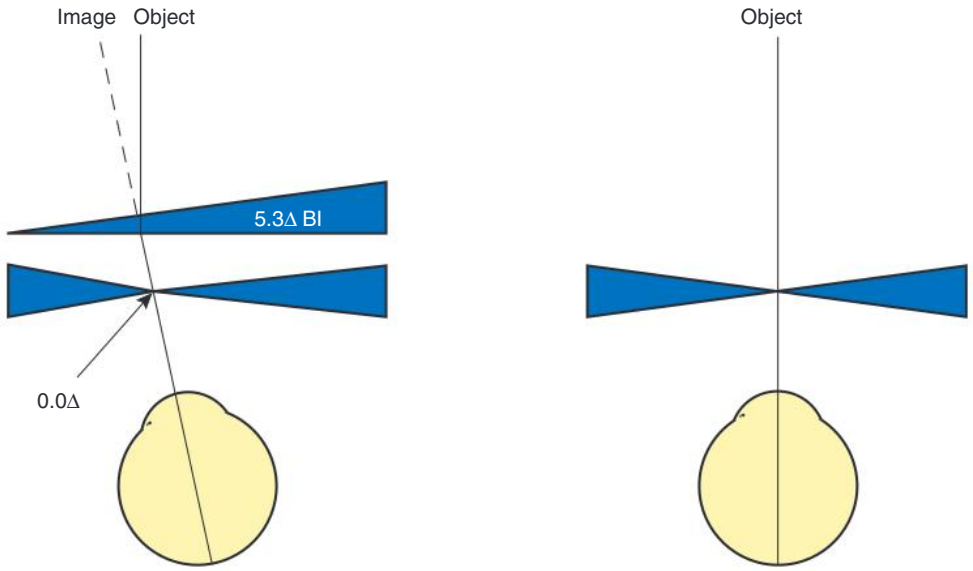

Figure 20.30 If the monocular interpupillary distance were to be altered to compensate for prismatically induced eye movement and correct progressive corridor placement, the net effect would be to change the amount of prism in the prescription. The decentration prism resulting from eye movement caused by the measuring prism will no longer be present. To maintain the correct amount of prism, the prescribed prism should be changed from 6.00Δ to 5.30Δ (rounded to 5.25Δ) of base-in prism. (From Brooks CW, Riley HD. Effect of prescribed prism on monocular interpupillary distances and fitting heights for progressive add lenses. *Optom Vis Sci* 1994;71:403. Figure 6.)

maintain the prescribed optical effect is no different than changing sphere and cylinder power in response to a change in lens vertex distance (see Chapter 14). Changing the amount of "prescribed prism" to compensate for decentration prism does not change the prescription.

SUMMARY

Prescribed vertical prism in progressive add lenses requires that the fitting cross be moved up or down by an amount equal to 0.3 times the prism amount. The direction of movement is opposite from the base direction of the prism.

Prescribed horizontal prism in progressive add lenses requires that the monocular PDs be increased or decreased by an amount equal to 0.3 times the prism amount. The direction of eye and MRP movement is opposite to the base direction of the prescribed prism. Steps to take when modifying fitting cross height are found in Box 20.4, *A*. Steps to take when modifying monocular PD amounts are summarized in Box 20.4, *B*.

Changing the amount of prescribed prism should be done only if there would be clinically significant changes to the prescribed prism. This does not happen unless the prescribed prism is greater than or equal to 6.00Δ *and* the refractive power in the prism meridian is greater than plus or minus 2.50 D. If this is the case, then prescribed prism may be altered according to the summary found in Box 20.5.

BOX 20.4 Compensating Fitting Cross Height or Monocular PDs for Prescribed Prism

A. How to Compensate Fitting Cross Height for Prescribed Vertical Prism
1. Measure the fitting cross heights.
2. Multiply the amount(s) of prescribed vertical prism by 0.3.
3. If the prism is base down, raise the fitting cross height by the calculated amount. If the prism is base up, lower the fitting cross height by the calculated amount.

B. How to Compensate Monocular PDs for Prescribed Horizontal Prism
1. Measure monocular PDs using a pupillometer.
2. Multiply the amount(s) of prescribed horizontal prism by 0.3.
3. Modify the monocular PD(s) by the calculated amount, increasing the PD for base-in prism and decreasing the PD for base-out prism.

BOX 20.5 Clinically Significant Prism Changes

Compensation Used If Modifying the Monocular Interpupillary Distances Produces Clinically Significant Changes in Prescribed Prism

It is suggested that compensation be considered *clinically significant* if moving the MRP will cause a change in prismatic effect of 0.50Δ or more. A change of at least 0.50Δ will occur if the prescribed prism totals ≥6.00Δ *and* refractive power in the meridian of movement is ±2.50 D or greater.

1. When horizontal prism is present, find the power of the lens in the horizontal meridian. When vertical prism is present, find the power of the lens in the vertical meridian.
2. Multiply the power in the meridian of eye movement by the change in monocular PD or change in fitting cross height. That is,

$$\Delta = cF$$

where Δ = change in prescribed prism power, c = change in PRP location in centimeters, and F = power in the meridian of PRP movement.

3. For minus lenses, subtract this amount from the prescribed prism. For plus lenses, add this amount to the prescribed prism.

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PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. Which factor is normally *not* considered essential in fitting the progressive add lens?
   - **a.** a good pantoscopic angle
   - **b.** a short vertex distance
   - **c.** a sufficient vertical frame dimension
   - **d.** monocular instead of binocular interpupillary distance (PD) measurements
   - **e.** specifying the nasal rotation of the progressive channel
2. A progressive lens wearer comes into the office. The left lens is missing. Both the frame and the remaining lens are in good condition. She has her prescription. You are able to identify the lens design from the semivisible markings on the lens. You remark the fitting cross and measure the right lens-fitting cross height as 22 mm. You then have the person wear her frame and remeasure both fitting cross heights. The right eye height measures 21 and the left 20. What fitting cross height would you order for the left lens?
   - **a.** 23 mm
   - **b.** 22 mm
   - **c.** 21 mm
   - **d.** 20 mm
3. When children who are 7 years of age or younger are fit with progressive addition lenses, yet still have the ability to accommodate just as other children do, the fitting cross is usually fit at which level?
   - **a.** at the lower lid.
   - **b.** in the center of the pupil.
   - **c.** 2 mm below pupil center.
   - **d.** 2 mm above pupil center.
   - **e.** 4 mm above pupil center.
4. True or false? Progressive lens-fitting crosses should be set lower for the first-time wearer to aid in adapting to the lenses.
   - **a.** True
   - **b.** False
5. True or false? Prism is verified at a different location on the progressive add lens from where the distance power is verified.
   - **a.** True
   - **b.** False
6. True or false? The fitting cross is at the major reference point.
   - **a.** True
   - **b.** False
7. True or false? When a progressive lens design changes as add power changes, the lens is called a multidesign lens.
   - **a.** True
   - **b.** False
8. Although all of the factors listed below are important in the fitting of progressive addition lenses, which factor has the most influence on wearer satisfaction?
   - **a.** Fitting accuracy
   - **b.** Brand of progressive lens chosen
   - **c.** Type of lens material selected
9. True or false? In practice, the power of the near addition is seldom measured when verifying progressive lenses.
   - **a.** True
   - **b.** False
10. Which of the following is *not* a suggested method for viewing the semivisible markings on a progressive addition lens?
    - **a.** Hold the lens so that its surface may be viewed in a mirror by reflected light.
    - **b.** Backlight the lens, and hold it in front of a black background.
    - **c.** Hold the lens up so that it may be viewed with a fluorescent light source behind it.
    - **d.** Use an instrument especially designed for the purpose that both illuminates and magnifies the lens surface.
    - **e.** All of the above are recommended methods for viewing the semivisible surface markings on a progressive addition lens.
11. A frame has been selected for a progressive addition lens wearer. Of the frame and fitting parameters listed below, which is least likely to be problematic?
    - **a.** The laboratory order form specifies a binocular distance PD = 65 mm.
    - **b.** The frame is an aviator shape.
    - **c.** After being adjusted, the pantoscopic tilt of the frame is 12 degrees.

12. True or false? When a wearer does come back with a complaint, the most straightforward way to check for possible problems is to first put the progressive markings back on the lenses and see if they are correct in relation to where they should be when the prescription is worn.
    a. True
    b. False
13. A standard progressive addition lens pair has been fit with the fitting crosses considerably lower than they should have been. Which of the problems listed below might this cause?
    a. The usable horizontal width of the intermediate portion of the lens corridor will be reduced.
    b. The wearer will have to tilt the head back too far to read.
    c. There may be an insufficient reading area if the frame has a narrow B dimension.
    d. All of the above may be caused by this fitting error.
14. Unwanted peripheral cylinder power in a progressive add lens
    a. decreases with increase in add power.
    b. increases as the add power increases.
    c. is equal to the cylinder in the distance prescription.
    d. is independent of add power.
15. True or false? Compared with a soft design, a hard design usually provides a wider area of high visual acuity in the distance portion of the lens.
    a. True
    b. False
16. Progressive power can change from distance to near zones in either a rapid or slow fashion. If it changes in a rapid fashion, then which of the following is *not* likely?
    a. The lens has a short progressive corridor.
    b. The intermediate zone width will generally be smaller.
    c. The near zone is generally smaller.
    d. There is more unwanted peripheral cylinder.
17. True or false? Distance and intermediate and near zone widths all influence each other. When one zone is made larger or wider, the other two zones will become narrower and smaller.
    a. True
    b. False
18. Which of the following are not demonstrated by contour plots?
    a. Relative progressive zone width
    b. The presence of a hard or soft optical design
    c. The anticipated amount of unwanted astigmatism in the upper half of the lens
    d. The expected increase or decrease in chromatic aberration throughout the lens
    e. Where certain blur zones may fall
19. Is a progressive addition lens specifically designed for frames with a short B dimension more likely to resemble a hard or a soft design?
    a. a hard design
    b. a soft design
    c. There is no way to tell.
20. A presbyope with no needed distance prescription is accustomed to crystal clear distance vision. Is he more likely to complain about a progressive addition lens with a hard design or one with a soft design?
    a. One with a hard design
    b. One with a soft design
    c. It is difficult to make this kind of prediction.
21. Which lens type listed below does *not* require a free-form type of lens generating to make the lens?
    a. position-of-wear progressives
    b. lenses with the add power split between front and back lens surfaces
    c. lenses that are personalized with the width of the progressive zone based on wearer eye movement preferences
    d. progressives made with atoric curves
    e. progressives made as semifinished lenses and completed in the laboratory
22. Position-of-wear lenses are able to correct or compensate for all but which of the following?
    a. a difference in the vertex distance between the refraction and the wearer's glasses
    b. a pantoscopic tilt of the lenses that was not present during refraction
    c. a changing base curve requirement based on lens power
    d. varying amounts of induced oblique astigmatism in the two power meridians of a spherocylinder lens using an atoric surface
    e. Position-of-wear lenses can correct for all of the above.
23. True or false? Degressive lenses are used for small office environments, and all have 50% of the add power in the upper portion of the lens.
    a. True
    b. False
24. Near variable focus lenses have a power degression. Degression is
    a. the difference between prescribed distance and near power but going from near to far.
    b. the range in power of a variable focus lens from the total near power of the lens to the power found at the top of the lens.
    c. the range in power from the near portion to the midlevel of the lens.
    d. the range in power from the near portion to the fitting cross.
25. Suppose a degressive lens made by a certain manufacturer comes with a degression of 1.25 D for wearers who have a +2.25 add. This particular wearer has a distance correction of $+0.75 - 0.75 \times 090$ for both right and left lenses and a +2.25 add. What power would be verified in the upper portion of the lens?
    a. $+3.00 - 0.75 \times 090$
    b. $+1.75 - 0.75 \times 090$
    c. $+2.00 - 0.75 \times 090$
    d. $+1.25 - 0.75 \times 090$
    e. $+1.00 - 0.75 \times 090$
26. A degressive lens has a $+1.25 - 0.50 \times 010$ power in the upper portion of the lens. It has a power of $+2.75 - 0.50 \times 010$ in the lower portion of the lens. What is the degression (power range) of the lens?
    a. 0.75 D
    b. 1.25 D
    c. 1.50 D
    d. 1.75 D
    e. 2.75 D
27. True or false? No occupational progressive lenses meant for small offices and computers come with distance powers in the top of the lens. The top of the lens will only contain intermediate powers.
    a. True
    b. False

28. Using the rule of thumb for prism thinning of progressive addition lenses, how much prism thinning would be expected for the following prescription? (Remember that the rule of thumb is an approximation and is not exactly what might be received from an optical laboratory with a computer program that custom calculates yoked base-down prism based not only on distance power and near add, but also on the size and shape of the frame.)
R and L distance powers: +3.00 − 0.75 × 090
Add power: +2.25 D
a. No prism
b. 0.75Δ base down
c. 1.12Δ base down
d. 1.50Δ base down
e. 2.25Δ base down

29. A prescription reads as follows:
+2.00 D sph 3Δ BD
+2.00 D sph 3Δ BU
Add = +2.25 D
Fitting cross heights measure:
R: 20 mm
L: 20 mm
What fitting cross heights would need to be ordered to compensate for the prescribed vertical prism?
a. R: 19 mm, L: 21 mm
b. R: 21 mm, L: 19 mm
c. R: 20 mm, L: 22 mm
d. R: 22 mm, L: 20 mm
e. R: 20.5 mm, L: 19.5 mm

30. A prescription reads as follows:
−1.25 − 0.50 × 180 sph 5Δ BI
−1.25 − 0.50 × 180 sph 3Δ BI
Add = +2.25 D
Monocular PDs:
R: 30 mm
L: 30.5 mm
What monocular PDs would need to be ordered to compensate for the horizontal prescribed prism?
a. R: 28.5 mm, L: 29.5 mm
b. R: 31 mm, L: 31 mm
c. R: 31.5 mm, L: 31.5 mm
d. R: 32 mm, L: 31 mm

31. A prescription reads as follows:
−5.00 D sph 3Δ BI
−5.00 D sph 3Δ BI
Add = +2.00 D
Monocular PDs:
R: 31 mm
L: 31 mm
The PDs and fitting cross heights were measured without lenses in place, and there was no manifested tropia (i.e., the eyes did not appear to be turned outward). Because of the amount of prescribed prism, monocular PDs would need to be increased to 32 mm each. However, because of both the amount of prism present and the power of the lens in the horizontal meridian, the amount of prescribed prism should be modified. How should the new amount of prescribed prism be changed?
a. Reduce the amount of prism to 2.25Δ for each eye.
b. Reduce the amount of prism to 2.5Δ for each eye.
c. Increase the amount of prism to 3.25Δ for each eye.
d. Increase the amount of prism to 3.5Δ for each eye.
e. The amount of prism should be left the same.

32. Here are some prescriptions. To maintain best horizontal placement of the progressive zone, you would alter the monocular distance PDs for each of these. For which prescription should you compensate the prism amount to exactly maintain the amount of prism you intended when you wrote the prescription?
a. R: −1.75 − 2.00 × 180 with 3.50Δ of base-in prism
L: −1.75 − 2.00 × 180 with 3.50Δ of base-in prism
b. R: +3.50 sphere with 2.00Δ of base-out prism
L: +3.50 sphere with 2.00Δ of base-out prism
c. R: +4.00 − 2.00 × 090 with 4.00Δ of base-out prism
L: +4.00 − 2.00 × 090 with 4.00Δ of base-out prism
d. R: −3.00 − 2.00 × 090 with 3.50Δ of base-in prism
L: −3.00 − 2.00 × 090 with 3.50Δ of base-in prism.

21

Anisometropia

INTRODUCTION

The more common occurrence for a pair of eyes with refractive error is that the error in both eyes is basically equal in both kind and amount. This is called *isometropia*. The condition in which there is a difference in refractive power between the left and right eyes is called *anisometropia*. Anisometropia can work to an individual's favor in presbyopia. When one eye is emmetropic and needs no correction and the other is somewhat myopic, such a person can avoid the need for reading glasses. One eye is used to see for distance vision, the other for near vision. In fact, such a situation is often created in contact lens wear and is called *monovision*. One contact lens contains a weak near correction instead of a distance correction so that a presbyopic individual can avoid having to wear glasses for reading.

On the whole, however, a significant amount of anisometropia ends up creating problems. With young children, an unnoticed difference in refractive error between the two eyes can result in the blurred eye failing to develop good visual acuity—a condition termed *amblyopia*. An amblyopic eye will be unable to obtain 20/20 vision, even when the refractive error is fully corrected. So it is important to correct for anisometropia as soon as it is detected.

When anisometropia is corrected with spectacle lenses, problems are not always over. The spectacle lenses themselves can create difficulties. Spectacle lenses worn at a distance from the eye will magnify or minify everything viewed through the lens. Different lens powers magnify different amounts. When one lens has a different power than the other lens, the image of an object seen through the right spectacle lens is not the same size as the image of that same object seen through the left eye's spectacle lens. The brain tries to fuse these two images into one single object.

Spectacle lenses have prismatic effects that increase with increasing lens power. Viewing an object below the optical center (OC) of a low-powered lens creates only a little image displacement. But viewing that same object at that same distance below the OC of the other more highly powered lens may cause a more significant displacement of the image. Since the two images appear to be at different locations, the two eyes have to turn downward by differing amounts to keep from seeing double.

This chapter talks primarily about those problems that arise as a result of anisometropia and what can be done to overcome them with spectacle lenses.

ANISEIKONIA

Aniseikonia is a relative difference in the size and/or the shape of the images seen by the right and the left eyes. This image size difference can be a result of the eyes themselves or can be produced by the optics of the correcting lenses.

Types of Aniseikonia

Physiologic Aniseikonia

Aniseikonia occurs in a limited but useful amount even for individuals with eyes that are identical to one another. Suppose a person turns their eyes to the left to look at an object. The right eye will be slightly farther away from the object than the left eye. The image of the object in the right eye will be slightly smaller than the image seen by the left eye. These size differences give clues that help in localizing the object in space. This type of aniseikonia is expected and is referred to as *physiologic* (or *natural) aniseikonia*. Any other aniseikonia present to a clinically significant degree is an anomaly and is called *anomalous aniseikonia* or just plain *aniseikonia*. Anomalous aniseikonia can be caused by either the anatomic structure of the eye or the optics of either the eye or the correcting spectacle lens.

Anatomic Versus Optical Aniseikonia

When aniseikonia is caused by the anatomic structure, it is referred to as *anatomic aniseikonia*. Anatomic aniseikonia can be caused by an unequal distribution of the retinal elements (rods and cones) of one eye compared with the other.

Aniseikonia may also be caused by the optics of the eye or the optics of a correcting lens. When aniseikonia is a result of the optics of the eye, it is called *inherent optical aniseikonia*. When it results from an outside source, as from correcting ophthalmic lenses, it is called *induced aniseikonia*.

Symmetrical Aniseikonia

One eye may see an image that is symmetrically larger than the other eye (i.e., it is equally larger in every meridian). This is called *symmetrical aniseikonia* (Figure 21.1). Another type of aniseikonia is still symmetrical but has a meridional size difference in a meridian of one eye compared with that of the other eye. This is called *meridional aniseikonia*. Meridional aniseikonia can be in horizontal, vertical, or oblique meridians (Figure 21.2).

Asymmetrical Aniseikonia

Asymmetrical aniseikonia occurs when there is a progressive increase or decrease across the visual field. The image for one eye will get progressively larger across the visual field (Figure 21.3). This does not occur naturally but occurs when a flat prism is placed before the eye.

Distortion is caused by plus and minus spectacle lenses. This is due to the variable base-toward-the-center effect of plus lenses and the base-toward-the-edge prismatic effect of minus lenses. Such variable magnification creates a form of asymmetrical aniseikonia. This was shown in Chapter 18, Figure 18.11 as pincushion and barrel distortion.

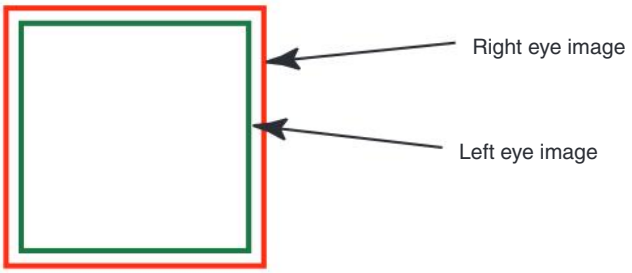
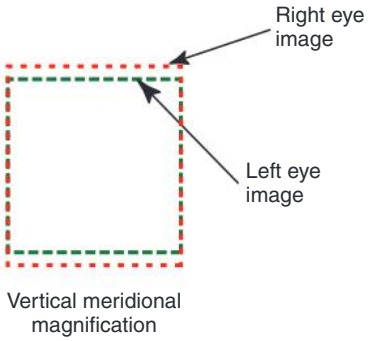


Figure 21.1 Symmetrical aniseikonia occurs when the image seen by one eye is equally larger in every meridian than the image seen by the other eye.



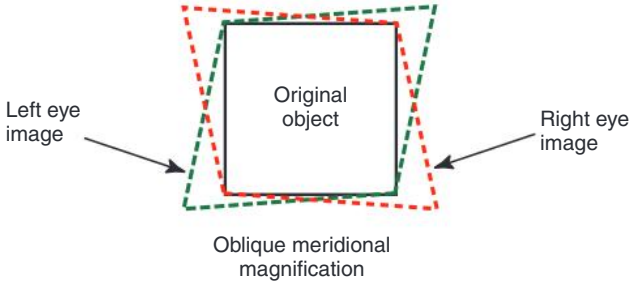


Figure 21.2 Meridional aniseikonia is still symmetrical but has a meridional size difference in a meridian of one eye compared with that of the other eye. Meridional aniseikonia can be in either horizontal or vertical meridians. In the *top* illustration, the aniseikonia is vertical. Meridional aniseikonia may also be found in an oblique meridian, as shown in the *bottom* illustration.

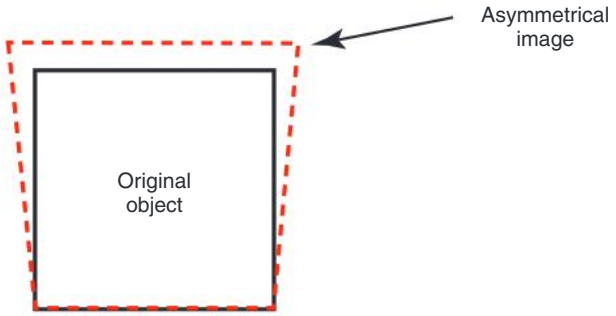


Figure 21.3 Asymmetrical aniseikonia is when there is a progressive increase or decrease across the visual field. The image for one eye will get progressively larger across the visual field as shown in this figure. This occurs when a flat prism is placed before one eye.

Spectacle Magnification: How a Spectacle Lens Changes the Image Size

In this section, we will look only at how a spectacle lens changes the magnification of an image for a single eye. We are not yet comparing differences in magnification between two eyes. The magnification change brought about by a single spectacle lens is called *spectacle magnification* (*SM*).

SM compares the size of the image seen by a person when wearing glasses with the size of the image seen when that same individual is not wearing glasses. In other words,

$$\text{SM} = \frac{\text{Retinal image size in corrected eye}}{\text{Retinal image in same eye uncorrected}}$$

This is expressed as a ratio, such as 1.04 or 0.96. As percentages these would be 4% magnification for a ratio of 1.04 and 4% minification for a ratio of 0.96.

There are two factors within a spectacle lens that contribute to magnification (or minification) of an image. One has to do with the power of the lens, and the other concerns how the lens is shaped. The shape factor has no net power to it yet can cause a change in magnification. This is like a telescope. A telescope changes the magnification of an object, but since the rays leaving the telescope are parallel, it could be said to have no net dioptric power. So think of a spectacle lens as two components:

1. An afocal (telescope-like) component
2. A power component

These components contribute to magnification independently. The afocal components of thickness, index, and front curve account for the shape factor; the power components of wearing distance and back vertex lens power make up the power factor (Figure 21.4). Their contribution to magnification can be given in the form of an equation for spectacle magnification, which is

$$\text{Spectacle magnification} = (\text{Shape factor}) \times (\text{Power factor})$$

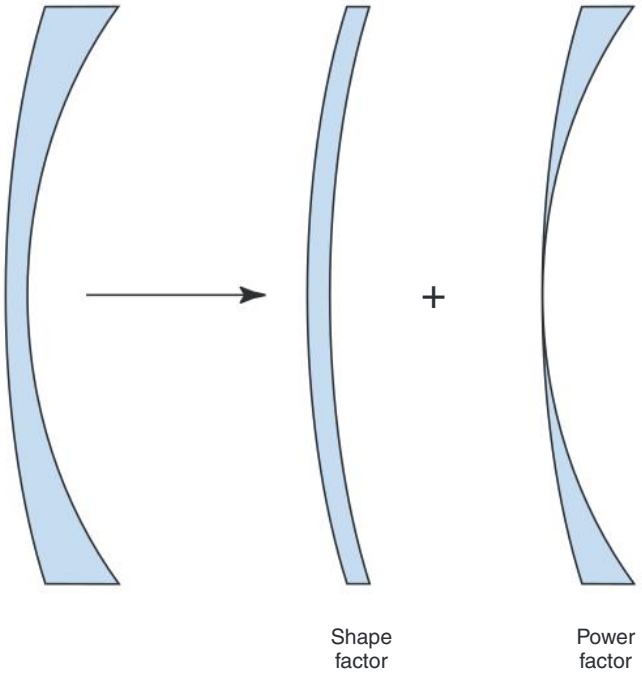


Figure 21.4 Spectacle magnification depends upon both the shape of a lens and the lens power. This figure attempts to conceptually separate these two factors into shape and power to help visualize those two aspects of spectacle magnification.

or

$$SM = \left(\frac{1}{1 - \frac{t}{n}F_1}\right)\left(\frac{1}{1 - hF_v'}\right)$$

where

t = the thickness of the lens in meters,
n = the index of refraction,
F_1 = the front surface refractive power of the lens,
F_v' = the back vertex power of the lens, and
h = the distance in meters from the back vertex of the lens to the entrance pupil of the eye. (The entrance pupil is normally assumed to be 3 mm from the front surface of the cornea.)

Here is an example of how spectacle magnification is calculated. (One should note that if the lens were to be toric, having a cylinder component, then each meridian would be calculated separately since each meridian would have its own back vertex power.)

Example 21.1

What is the spectacle magnification for a +5.00 D CR-39 lens having a +10.00 D front surface refractive power, a center thickness of 4.6 mm, and a 14-mm vertex distance?

Solution

The spectacle magnification formula is

$$SM = \left(\frac{1}{1 - \frac{t}{n}F_1}\right)\left(\frac{1}{1 - hF_v'}\right)$$

Remember that for h, the distance from the back vertex of the lens to the entrance pupil of the eye, we need to add the vertex distance (14 mm) to the distance from the front of the cornea to the entrance pupil of the eye (3 mm) to get the number needed. This is 17 mm but must be expressed in meters and equals 0.017 m. So we would substitute the following:

$$SM = \left(\frac{1}{1 - \frac{0.0046}{1.498}10.00}\right)\left(\frac{1}{1 - 0.017 \times 5.00}\right)$$
$$= 1.12752$$

A spectacle magnification of 1.1275 is the same as a 12.75% magnification.

Theoretically, What Was the Best Correction Thought to Be for Preventing Aniseikonia?

To answer this question, we need to know about two types of ametropia.

Axial and Refractive Ametropia

"*Ametropia* is the refractive condition in which, with accommodation relaxed, parallel rays do not focus on the retina."[1] Ametropia includes myopia, hyperopia, and astigmatism. Ametropia may occur because the axial length of the eye is either too short or too long. This type of ametropia is called *axial ametropia*. In other words, the refractive elements in the eye (the cornea and intraocular lens) are focusing light in the emmetropic amount, but the retina is not at the emmetropic location to receive the clear image. In contrast, the eyeball is of normal length in *refractive ametropia*, but it is the refractive elements of the eye that are not focusing light onto the retina. According to "classical theory" of aniseikonia, the type of ametropia determines how the aniseikonia is corrected.

Producing a "Normal" Image Size (Relative Spectacle Magnification)

Normal image size is customarily taken as the image size for a standard emmetropic eye with a +60.00 D refractive power. Suppose another eye, which is ametropic but corrected with spectacles, produces an image that is larger than the standard. The amount of magnification produced by this eye, relative to the standard eye, is called *relative spectacle magnification* (*RSM*). Expressed as an equation, relative spectacle magnification is

$$RSM = \frac{\text{Image size for a corrected ametropic eye}}{\text{Image size for a standard emmetropic eye}}$$

The difference between spectacle magnification and relative spectacle magnification is this:

- SM compares the image size of *one* eye in both uncorrected and corrected states.
- RSM compares an ametropic but corrected eye with a standard emmetropic eye (that does not need a correction).

It would be desirable to choose the type of refractive correction for myopia, hyperopia, and astigmatism that would produce a normal emmetropic image size.

Knapp's Law and Ametropia

If the ametropia is axial, optical theory predicted that the image size would be different from the emmetropic image size. According to *Knapp's law*, "When a correcting lens is so placed before the eye that its second principal plane coincides with the anterior focal point of an axially ametropic eye, the size of the retinal image will be the same as though the eye were emmetropic."[1]

Stated another way, Knapp's law says that using spectacle lenses on an axially ametropic eye (one that is longer or shorter than normal) will bring the retinal image size back to normal.

A refractively ametropic eye has a normal emmetropic axial length. The refractive elements such as the cornea and crystalline lens are what make the eye myopic or hyperopic. On this assumption, contact lenses, which do not provide the larger magnification or minification of spectacles, would maintain the already-emmetropic image sizes.

Thus, according to Knapp's law, we would expect that:

- For axial ametropia, the correction of choice would be spectacle lenses.
- For refractive ametropia, the correction of choice would be contact lenses.

Knapp's law provides some helpful trends in matching the type of refractive correction with the type of ametropia to equalize retinal image sizes. However, clinical studies have shown that patients often still experience aniseikonia even when the retinal image sizes are made equal. This suggests that the perception of aniseikonia is more a cortical phenomenon than a retinal one.[2,3] Long-standing axial ametropes may perceive no aniseikonia even while the actual retinal image sizes are different. In these cases, suddenly equalizing the retinal image sizes with spectacles using Knapp's law may induce a problem for the patient.[4] Therefore, contact lenses, which allow retinal image size differences between the eyes to persist, are often helpful even to axial ametropes.[5] Clinically, this results in contact lenses being the preferred refractive correction type for both axial and refractive ametropes.

In relation to image size correction, corneal refractive surgery should be considered similar to contact lenses since such surgery places the refractive correction at the same location as a contact lens.

For patients unable to pursue either contact lenses or refractive surgery or for patients who require a change in retinal image size to eliminate their perception of aniseikonia, spectacle lenses are the preferred treatment.

Detecting Clinically Significant Aniseikonia

Although there are both obvious and not-so-obvious signs and symptoms that may indicate clinically significant aniseikonia, it is sometimes difficult to recognize. Aniseikonia symptoms are often the same symptoms as experienced with uncorrected refractive errors or oculomotor imbalances. The difference is that with aniseikonia, symptoms either are not helped by the correction or appear after these other problems are corrected.

In addition to those just mentioned, here are some indications of clinically significant aniseikonia:

1. High anisometropia or high astigmatism
2. The presence of certain factors that physically alter the eye, such as pseudophakia, scleral buckling, corneal transplantation, refractive surgery, and optic atrophy[6]
3. Complaints about spatial distortion, such as slanting floors, tilted walls, or ground too close or too far away
4. Better optical comfort when only one eye is used

It is helpful to notice if the symptoms occurred after a prescription change or after the dispensing of new glasses. Assuming the refraction is correct and the lenses verify as they should, when anisometropia is present, aniseikonia is likely. There are several ways to approach the problem.

CORRECTING ANISEIKONIA WITH SPECTACLE LENSES

If an exact amount of aniseikonia is found, modifications to the spectacle lenses that change relative spectacle magnification will be of benefit whether the anisometropia is axial or refractive.[6] This is because there are specific modifications that can be made to spectacle lenses that will change their magnification. Even though contact lenses are usually indicated in the presence of aniseikonia, the patient may not want contact lenses. Changing base curves, lens thicknesses, and vertex distance can still be used with spectacles to correct the aniseikonia.

There are several ways to approach the problem of aniseikonia:

1. If you are concerned that aniseikonia might be a problem but have no clear evidence, use a "First Pass Method."
2. If you are fairly certain aniseikonia is present and want to address it yourself but have no way of measuring it, then make "directionally correct magnification changes" to each lens individually.
3. Estimate percent magnification differences based on the refractive prescription, and change lens parameters accordingly.
4. Measure the percent magnification differences between the two eyes, and change the lens parameters according to the results found.

Using a "First Pass Method" to Prevent Possible Problems

When there is a concern that aniseikonia might be a problem, there are some things that can be done with frame and lens choices that will reduce magnification differences between lenses that would otherwise occur. This can be done before anything else and will not hurt anything, even if aniseikonia is not a problem at all.

1. Use a frame with a short vertex distance and, if nose pads are present, further reduce the vertex distance.
2. Use a frame with a small eye size. This secondarily reduces vertex distance.
3. Use an aspheric lens design. This usually flattens the base curves.
4. Use a high-index lens material. This will thin plus lens center thickness.

Making "Directionally Correct" Magnification Changes

It is possible to really go after an aniseikonia problem you are fairly certain is present but have no way of exactly measuring. This is done by making changes to each lens individually in the appropriate direction so as to either reduce or increase magnification. Sometimes, it is possible to reduce magnification differences just enough to alleviate the problem without having an "exact fix." When using this approach, here are two important notes:

1. Remember that the greater the difference in right and left lens power is, the greater will the changes need to be to meet the problem. Changes will be to vertex distances, base curves, and lens thicknesses.
2. In your concern about the aniseikonia, do not forget that, with presbyopes, it may be necessary to correct for vertical imbalance at the same time.

What is done with each lens will depend upon the power of the right and left lenses compared with one another.

- If both lenses are plus, but one is more plus than the other, follow the instructions found in Box 21.1.
- If both lenses are minus, but one is more minus than the other, follow the instructions in Box 21.2.
- If one lens is plus and the other is minus, follow the instructions in Box 21.3.

Estimating Percent Magnification Differences

It is possible to estimate what the percent differences in magnification are from the prescription. Estimates of how much magnification changes per diopter of power vary. Linksz and Bannon[7] say we can expect 1.5% per diopter of anisometropia when anisometropia is refractive in origin. However, since the ametropia probably has at least some axial component, 1% per diopter is more realistic. One percent per diopter is now considered the rule of thumb.

To correct for estimated aniseikonia, we can figure that if there is a problem, it will probably be between 1% and 2%. How to make exact

BOX 21.1 If Both Lenses Are Plus (Anisohyperopia)

- Choose a frame with a minimum vertex distance.
- Keep the eye size small.

For the Higher Plus Lens	For the Lower Plus Lens
• Flatten the base curve	• Steepen the base curve
• Thin the lens as much as possible	• Increase center thickness. If possible, try not to go thicker than the center thickness of the higher plus lens
• Decrease the vertex distance	• If the edge is thick enough, move the bevel away from the front and toward the back of the lens. (Do not exceed the limits of cosmetic acceptability.) This moves the lens forward in the frame, increasing magnification

BOX 21.2 If Both Lenses Are Minus (Anisomyopia)

- Choose a frame with a minimum vertex distance.
- Keep the eye size small.
- It is not advisable to change base curves for minus lenses unless there is certainty of what the end result will produce. (If the lens is more minus than −2.00 in power, steepening the base curve alone may not do the expected. Steepening the base curve increases magnification, but it also increases the lens bend. This results in increased vertex distance.* Greater vertex distance for minus lenses means increased minification and may produce the opposite of intended results.)

For the Higher Minus Lens	For the Lower Minus Lens
• Decrease the vertex distance for this lens by moving the bevel as far forward as possible	• Increase the vertex distance by moving the bevel away from the front of the lens. (Moving it totally to the back is going to look bad.)
• If a large change in magnification is required, it may be necessary to steepen the base curve considerably. If this is done, then the lens also must be thickened and the bevel moved to the front surface to decrease the vertex distance. Unless this is done, steepening the base curve may not yield the desired results†	

*Each 1- D change in base curve changes vertex distance by approximately 0.6 mm.

†From Brown WL. The importance of base curve in the design of minus iseikonic lenses. *Optom Vis Sci.* 2006; 82(11):850–856.

BOX 21.3 If One Lens Is Plus and the Other Is Minus (Antimetropia)

- Choose a frame with a minimum vertex distance.
- Keep the eye size small.

For the Plus Lens	For the Minus Lens
• Flatten the base curve • Thin the lens • Decrease the vertex distance	• Decrease the vertex distance by moving the bevel to the front of the lens

When one lens is plus in power, some suggest the use of a high-index lens for the higher plus lens. This will reduce thickness, base curve, and, secondarily, vertex distance for the higher plus lens. A regular index lens is used for the lower plus (or minus) lens.

magnification changes by specifically changing lens parameters will be discussed later in the chapter.

(Note: At the time of this writing, screening devices that are used for estimating percent magnification are not likely to be accurate enough to be effective. Large image size differences result in loss of binocularity and produce no symptoms. Small differences are not accurately measured with screening devices and are the ones that cause the most problems.)

Measuring Percent Magnification Differences

The ideal way to correct for aniseikonia is to measure it directly. Historically the classical method was to quantitatively measure image size differences using a *space eikonometer*. Unfortunately, space eikonometers are no longer made.

An alternative method has been to use appropriate Keystone View stereoscopic cards, preferably in conjunction with the Keystone orthoscope (a stereoscope with "minimum-distortion" lenses). Another more accurate means of testing is the Awaya New Aniseikonia Test (Handaya Co Ltd, Tokyo, Japan).

Once aniseikonia testing is complete, it is still necessary to determine which parameters of each lens should be changed by what specific amount. There are tables, nomographs, and online calculators in existence that give expected changes in magnification produced by changes in base curve, lens thickness, vertex distance, and index of refraction.

Whenever looking at the magnifications for any given pair of lenses, there will typically be a difference between left and right spectacle lens magnifications. This difference does not have to be reduced to zero. Instead, the difference between the two spectacle lens magnifications should be reduced by an amount equal to the aniseikonia found between left and right eyes. (Even then, symptoms may disappear with smaller reductions in aniseikonia.)

Changing Parameters for Magnification Differences

Once percentage magnification differences are found, there are programs that allow the input of relevant lens parameters, including base curve, thickness, vertex distance, and index of refraction. By changing the parameters that are a part of the spectacle magnification formula, resulting lens magnification percentages are seen. One such possibility is found on the Chadwick Optical website at https://chadwickoptical.com/aniseikonia-calculator/.

Even if it is possible to measure the full percentage differences between left and right eye, it may not be necessary to fully correct those differences. This is especially heartening when attainment of a full magnification difference correction could result in extremely unusual lenses with very thick centers or an inappropriately steep base curve on one of the lenses.

When using such programs or when simply making changes in lens shapes to affect magnification in other aniseikonia situations, here are some points to consider (refer also to Boxes 21.1 to 21.3).

1. Just reducing the vertex distance for both lenses will help.
2. Changing the base curve of even one lens may also help. (Reducing the highest base curve to equal the lower base curve can make a big change in magnification difference.)
3. Use an aspheric design. For plus lenses, both base curves will be flatter. This allows a decrease in thickness of the thicker lens. The thinner lens may then be made equal in thickness to the thicker lens.
4. Increasing the index of the lens will thin the lens.
5. If the least plus lens is thick enough, it may be possible to move the lens forward in the frame by moving the bevel back on the lens. This increases vertex distance.
6. It is possible to get a bit more of a change in magnification difference in plus lenses by leaving the weaker lens as a nonaspheric lens with a steeper base and using an aspheric design for the stronger lens.
7. Use an antireflection coating on both lenses to reduce lens visibility and any otherwise noticeable differences between the two lenses.

Size Lenses

A size lens is one that is made to change magnification by a certain percentage. Size lenses made with zero dioptric power do not change the vergence of light as it passes through the lens—only the magnification of the image. Size lenses with zero dioptric power can be made into a diagnostic set of trial size lenses, each with its own percent

magnification. Such lenses can be useful in determining the appropriate amount of aniseikonic correction.

Size lenses also refer to corrective lenses made to correct magnification differences that also include dioptric refractive corrections for myopia, hyperopia and astigmatism.

What Is a Bitoric Lens?

It is possible to have a difference in magnification between two major meridians in right and left eyes. Magnification can be changed in each meridian independently.

Normally, a spherocylinder lens has a front surface that is spherical and a back surface that is toric. The toric surface has a different radius of curvature in each of the two major meridians, thereby correcting for the astigmatism. However, it is possible to put a toric surface on the front of the lens *and* on the back of the lens, even if that lens is a sphere. This would happen if one chooses differing front lens curves for the purpose of creating more magnification in one meridian than the other. If this is done, then back-surface curves are selected so as to counteract the cylinder power created by the toric front surface. This lens with toric surfaces on both the front and the back is called a *bitoric* lens (Figure 21.5).

Irregular Aniseikonia

An irregular amount of aniseikonia may be retinally induced. Sometimes, there are large and irregular amounts of aniseikonia even in the absence of refractive differences between left and right eyes. These large and irregular amounts may occur in but are not limited to cases such as epiretinal membrane, a reattached retinal detachment, macular hole, or macular edema.[8] Retinally induced aniseikonia is difficult to deal with because correcting with one magnification over the entire visual field leaves magnification differences in other parts of the visual field and "because it is visual field angle dependent, it cannot be corrected fully."[8]

How Helpful Is Correcting for Aniseikonia?

It would be logical to consider just how helpful it is to go to the trouble of making lens changes to correct for aniseikonia when in practice these changes are not always done. In a study done at Emory Eye Center, Achron et al.[6] compared corrections for 34 anisometropes. They found that modifying lens design to equalize relative spectacle magnification both reduced aniseikonia and improved subjective comfort and performance. At the conclusion of the study, 93% of the study subjects preferred the spectacles that had been modified to correct for aniseikonia over traditional spectacles.

Their results also found that, contrary to Knapp's law, axial and refractive anisometropes both benefitted from modifications to relative spectacle magnification.

PRISMATIC EFFECT OF LENS PAIRS

When depicting the optics of a pair of spectacles, the wearer is normally shown looking directly through the OC of both lenses. This situation, of

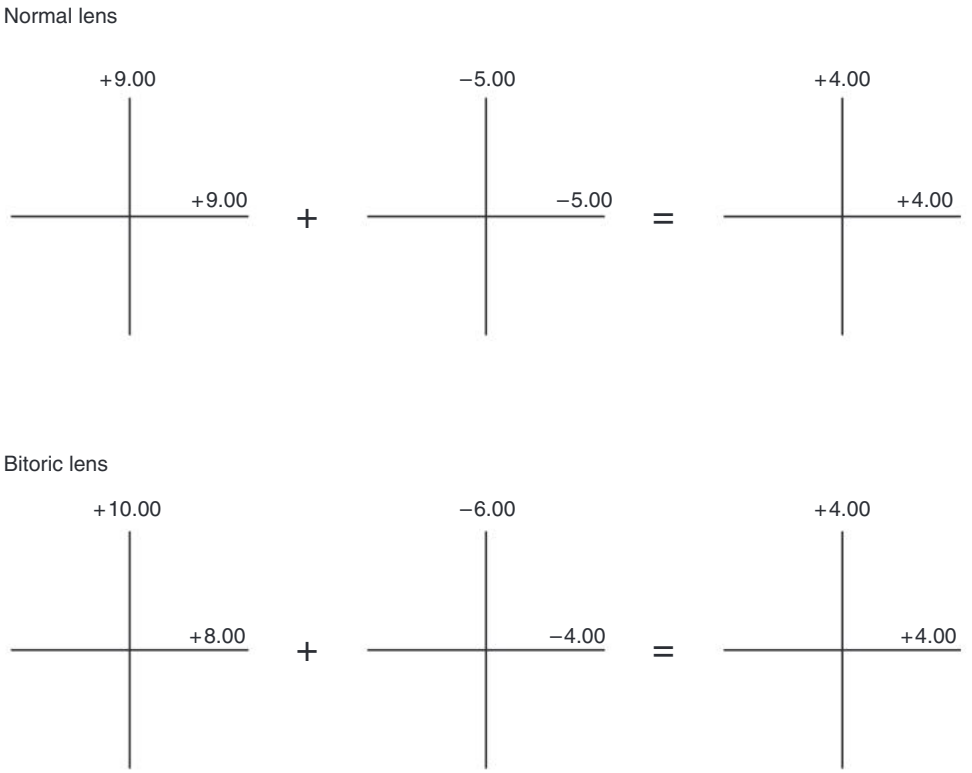


Figure 21.5 Normally, a sphere lens with no cylinder power has a spherical curve on both front and back surfaces. This is represented by the first set of power crosses in which the front surface has a power of +9.00 D and the back surface −5.00 D. Ignoring lens thickness, the resulting lens power will be +4.00 D sphere. Next is an example of a bitoric lens. A lens is to have a power of +4.00 D sphere. The lens can be made with a cylinder on the front, as shown for the bitoric lens. As long as the second surface curves counteract the powers of the toric front surface, the lens can still end up with a power of +4.00 D sphere. Such a lens will produce differing magnifications in each meridian.

course, occurs only part of the time because the wearer's direction of gaze changes behind the lenses.

When looking to the right, left, upward, or downward, because the object viewed is seen through a noncentral lens area, there is a prismatic effect induced by each lens. This prismatic effect is predictable and may be calculated using Prentice's rule.

If both right and left lenses are equal in all respects, then the prism powers induced by the two lenses for any position of gaze are also equal.

Example 21.2

A man wearing −3.00 D lenses for both eyes turns his eyes to look at a distant object on his right. In so doing, he looks through a point on his lenses 1 cm to the right of the OCs (Figure 21.6). What is the resultant prismatic effect for each eye?

Solution

Using Prentice's rule, it may be seen that

$$\Delta = cF$$

and in this case,

$$\Delta = (1)(3.00) = 3.00\Delta$$

Therefore, there is 3.00Δ of prism induced by the right lens and 3.00Δ of prism induced by the left. Base direction is base out for the right eye and base in for the left. As seen from Figure 21.6, these effects are both base to the right. As a result, the eyes remain parallel and are forced neither to turn inward (converge) nor outward (diverge) in their orientation to one another.

Anisophoria

Remember that the condition of the eyes whereby a person requires lenses that differ in power—one lens being stronger or weaker than the other—is known as *anisometropia*. When such a person looks at an object through corresponding points on the lenses other than the OCs, the prismatic effects that are induced will be unequal for each eye. This situation is referred to as *anisophoria*.

Example 21.3

Suppose a prescription of the following power is worn:

O.D. −7.00 D sphere
O.S. −3.00 D sphere

What prismatic effects are induced by the lenses for the points 1 cm to the right of the OCs when viewing a distant object located to the right (Figure 21.7)?

Solution

For the right eye, the prismatic effect is found (using Prentice's rule) as

$$\Delta = cF$$
$$\Delta = (1)(7.00) = 7.00\Delta$$

For the left eye, the effect results in 3.00Δ of prism.

In Example 21.2 in which both lenses were of identical power, there was no imbalance between the eyes. Both eyes continued to point in the same direction. In Example 21.3, however, the right eye is forced to turn approximately 4.00Δ more than the left. Because the base-out effect overpowers the base-in effect, the net effect for the two eyes is approximately 4.00Δ base out. The eye turns toward the apex of the prism, and the two eyes are forced to converge relative to one another. Fortunately, the eyes are not required to hold this position over long periods of time and quickly adapt to the variations of fixation. (Note: The word *approximately* is used because basing prismatic imbalance on Prentice's rule alone is a simplified yet oft-accepted method of calculation. This approximation happens with both horizontal and vertical imbalance and is explained later in the chapter under the section entitled Remole's Method.)

VERTICAL IMBALANCE

Just as differential prismatic effects are present with anisometropia when looking left and right, different vertical prismatic effects will also be present when looking up or down. The most troublesome situation

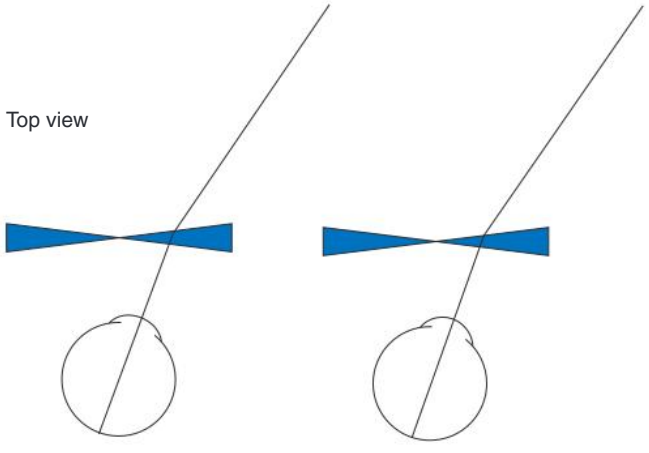


Figure 21.6 Light from an object at infinity when viewed through the periphery of prescription spectacle lenses is deviated by the prismatic effect of the lenses. When both lenses are of the same power, that deviation is symmetrical. Both rays emerging from the lenses, although deviated, are still parallel. Therefore the eyes neither converge nor diverge relative to one another.

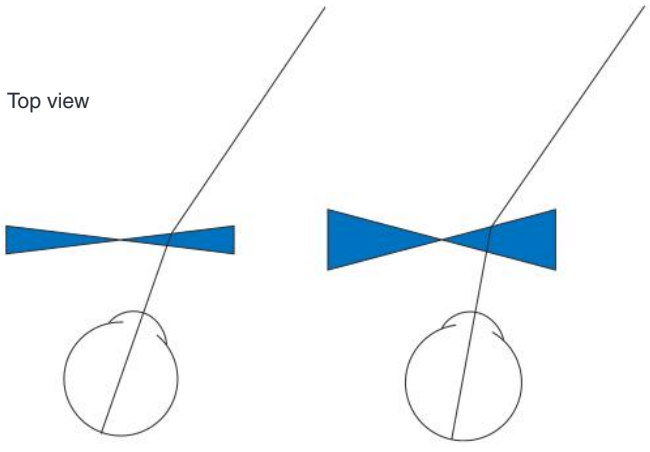


Figure 21.7 When parallel light from a peripherally viewed object at infinity strikes a pair of spectacle lenses with powers that are unequal, the prismatic effects created at these noncentral lens positions are unequal, causing more deviation for light entering through one lens than through the other. This, in turn, causes either a convergence or divergence of the eyes, depending on lens powers.

may occur with reading or close work over an extended period of time. When the wearer drops the eyes below the OCs of the lenses and unequal vertical prismatic effects result, the differential prismatic effect induced is referred to as *vertical imbalance*.

To understand vertical imbalance, consider the same person whose prescription was

O.D. −7.00 D sphere
O.S. −3.00 D sphere

If that person now looks 1 cm below the OCs, the prismatic effects induced will be O.D. 7.00Δ base down and O.S. 3.00Δ base down (Figure 21.8). The net result is approximately 4.00Δ of base-down prism before the right eye.

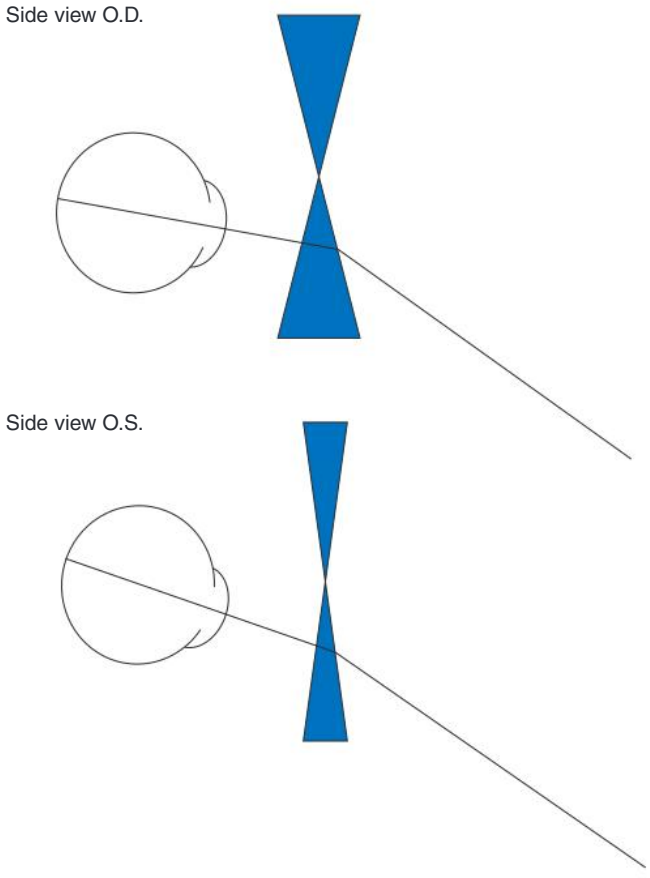


Figure 21.8 Unequal lens powers also cause the same type of prismatic imbalance for objects viewed through tops and bottoms of spectacle lenses as was seen in the previous figure when looking left or right. Unfortunately, the problem created is harder for the eyes to overcome, since turning one eye farther up or down than the other is not a natural paired eye movement. (Note: This figure is drawn with the assumption that both eyes will be looking through points on the lenses that are the same distance below optical centers. This is because the typical method of using Prentice's rule for vertical imbalance makes this assumption. This assumption is made to simplify vertical imbalance calculation. In reality, since the right eye does not turn as far downward due to the stronger base-down effect of the higher minus lens, the right eye will be looking through a point further up in the lens than shown here. A careful viewer will notice that the center of rotation of the right eye is intentionally but incorrectly drawn at a level relatively lower than that of the left eye. For more on this topic, see the section found later in this chapter entitled *Remole's Method*.)

Who Is Responsible for Correcting Vertical Imbalance?

Vertical imbalance often goes unnoticed throughout the eye examination and dispensing processes. This may happen for a variety of reasons. One major reason, however, is that unless segment or progressive addition lens measurements are known, the amount of imbalance cannot be determined. These measurements are not known until after frame selection has occurred. Ideally, the prescriber should notice the need and call for a correction on the prescription. This does not always happen. Therefore, unless dispenser and examiner are working in close proximity, the responsibility will rest with the dispenser. The dispenser must recognize when a vertical imbalance correction is needed.

When Is a Correction for Vertical Imbalance Needed?

The need for a vertical imbalance correction should be addressed when an anisometropic wearer progresses from single-vision lenses into multifocal lenses.

For the single-vision lens wearer, if the unequal vertical prism proves troublesome with the eyes dropped for reading, simply dropping the head will solve the problem. In this manner, both lines of sight pass through the OCs, where there is a net prismatic effect of zero. This alleviates the problem. For the new multifocal wearer, the option of turning the head downward is eliminated by the positioning of the segment. To read through the bifocal portion, the wearer *must* lower the eyes and use a noncentral portion of the lens. The same occurs for the progressive addition lens wearer.

Tolerance to vertical imbalance in the reading area varies from person to person. Generally, any time there is a vertical meridian difference greater than 1.50 D in power between right and left lenses, vertical imbalance problems are a possibility; when power differences are greater than 2 to 3 D, vertical imbalance correction merits consideration. Some individuals with anisometropia are sensitive to the imbalance, whereas others with an even higher amount may appear not to be bothered. Some of these may either compensate by either developing a greater range of vertical fusional ability or learning to suppress one of the images.[9] Observing the individual while he or she is reading through the old anisometropic single-vision prescription may give a clue as to possible difficulties.

To determine if a vertical imbalance correction may be needed, hand the person a reading card and ask him or her to read something. Notice what the person does when handed the card. If the individual drops the eyes to read, he or she is accustomed to reading with vertical imbalance and no special compensation may be necessary. If the person drops the head to read, however, reading is being done through the distance OCs to prevent prism imbalance in the lower part of the glasses. These individuals may experience difficulty with a multifocal lens if the imbalance is left uncompensated. In some instances, only partial compensation for the imbalance may be required.

Vertical imbalance corrections are especially critical when the imbalance is of recent onset. This occurs when a person has had either cataract surgery or refractive surgery on one eye only. Both situations create anisometropia, causing a vertical imbalance at near for which a multifocal wearer is unable to compensate. In these cases, because adaptation has not occurred over time, the full amount of imbalance correction is indicated.

It should be especially noted that *the hallmark symptom* of a vertical imbalance induced by spectacles is the wearer complaining of vertical double vision only while looking down to read. This is true whether the vertical diplopia is of recent onset or not.

CORRECTING FOR VERTICAL IMBALANCE

There are several methods of correcting for vertical imbalance, some of which are capable of compensating for more prismatic imbalance than others. The first four on the list attempt to avoid the problem

of vertical imbalance. The last three attempt to correct for the problem.

1. Contact lenses
2. Two pairs of glasses
3. Dropping the major reference point (MRP) height
4. Raising the seg height
5. Fresnel press-on prism
6. Slab off (bicentric grind)
7. Dissimilar segs

It should be noted that those who benefit from the correction of vertical imbalance will also benefit from a good choice of lens parameters for offsetting aniseikonia (image size differences). Lens choices for aniseikonia were explained earlier in this chapter.

Contact Lenses

From a purely optical standpoint, one of the best options available for correcting vertical imbalance is the contact lens. The optical center of the contact lens moves with the eye. When an individual wears contact lenses, the spectacle lens-induced prismatic difference disappears and the vertical imbalance problem disappears with it.

Two Pairs of Glasses

When anisometropes wear single-vision lenses, vertical imbalance seldom surfaces as a problem. This is because single-vision lens wearers have the option of dropping the head and looking through the lens optical centers instead of just dropping the eyes and looking below the optical centers. This means that if an anisometrope decides against multifocal lenses, he or she is not forced to look into the lower portion of the lens where the near segment is located. Thus, one option for overcoming vertical imbalance is to have *two pairs of single-vision glasses*, one for distance and one for near. When using two pairs of glasses, the reading glasses should be ordered with the optical centers lower in the frame than normal. This way the wearer looks through the lens optical centers. A separate pair of single-vision glasses for near does not *correct* for vertical imbalance; it *avoids* vertical imbalance. When ordering two pairs of glasses for this purpose, it is advisable to position the optical centers for the near prescription 5 mm below the vertical center of the frames.

Instead of using a regular frame for the near glasses and lowering the optical centers, a pair of half-eye frames may be used. In this way, the optical centers are relatively lower compared to the eyes, even at their normal locations. They do not have to be lowered farther.

Dropping the Major Reference Point Height

Reducing the amount of vertical imbalance at near by dropping the vertical position of the OC or MRP of a multifocal lens pair is used in practice but is not as optically sound as other options. By dropping the OC, the distance from the OC to the reading level is reduced and so is the prismatic effect at near. Lowering the OC, however, will transfer imbalance from the near portion to the distance portion. This is because what is gained at near is offset by an increase in imbalance in the upper portion of the lens. Dropping the MRP in multifocal lenses might be successful in borderline cases of imbalance but is not the best option available.

Raising the Seg Height

By raising the seg height *without* simultaneously raising the height of the distance OC (i.e., the MRP), the wearer will not have to look as far down into the lens at near. If the eyes are not as far from the distance OCs for reading, the vertical imbalance will not be as great.

If the surfacing laboratory moves the distance OC up as the seg goes up, however, then no benefit is derived. If the technique of raising the seg is to be used, it is best to specify not just the seg height but also the MRP height.

In addition, there is a limit as to how high the segment should be raised before it interferes with distance vision. In no case should the segment height be higher than the location of the MRP.

Fresnel Press-On Prism

Fresnel press-on lenses and prisms are made from "thin, transparent, flexible, plastic material which adheres to the surface of an ophthalmic lens when pressed in place."[1] Thus it is possible to cut a Fresnel press-on prism to fit the lower half of one lens to counteract a vertical imbalance. Placed on the back surface of the ophthalmic lens, the Fresnel prism simulates a slab-off lens. Fresnel lenses for such an application are usually not considered to be a permanent solution but rather are used on a trial basis to see if the wearer's visual difficulties can be alleviated. (For more on Fresnel lenses and prisms, see Chapter 17.)

Slab Off (Bicentric Grinding)

The most common option for correcting vertical imbalance produces a vertical prismatic effect in the lower half of one lens only. For segmented bifocal lenses, the correcting prism begins at the level of the bifocal segment line. This type of correction is called a *slab off*, or a *bicentric grind*. It is identified by the presence of a horizontal line across the entirety of one lens. For a segmented multifocal, this line is set to match the line of the near reading segment.

Slab off is almost always used unless the amount of correction required is less than 1.50Δ, although some labs are able to produce a lens with less than 1.50Δ of slab-off prism. For low amounts of slab-off prism, it is difficult to control the appearance and placement of the slab line. Fortunately, problems with vertical imbalance do not occur as frequently once vertical imbalance drops below 1.50Δ. On the other hand, slab off can be made in fairly large amounts.

Slab off can be custom ground on any lens whether it is made from glass or plastic.

Fabrication of Base-Up Slab-Off Prism

Figure 21.9 shows the result of adding base-up slab-off prism to the lower half of a spectacle lens. This can be accomplished several different ways depending on the lens material and technology available to the lab. Although the details of the exact fabrication method may vary, slab off results in base-up prism being added to the bottom part of the spectacle lens. In reality, one can see from Figure 21.9 that a corresponding amount of base-down prism has been surfaced away from the lower half of the lens. This loss of base-down prism is equivalent to the addition of base-up prism. This loss of lens material at the bottom edge of the lens also helps to remember why slab off is always prescribed for the lens with the higher minus (or least plus) power in the 90th meridian, because that is the lens that starts with the thicker bottom edge.

With flat-top segmented multifocal lenses, the completed lens grind produces a relatively inconspicuous line. This line follows the flat-top seg line already present on the lens and is partially obscured by it (Figure 21.10). Although any shaped seg, or even no seg at all, may be used in conjunction with bicentric grinding, the flat-top seg gives good results cosmetically.

Slab Off With Progressive Addition Lenses

Because there are no visible lines with progressive addition lenses as there are with segmented multifocals, it would be easy to conclude that slab off is not an option for progressive addition lenses. This is not the case. Just as it is possible to put slab off on single-vision lenses, so also is it possible to use this vertical imbalance correction method on progressive addition lenses.

Sheedy reports that slab-off prism on a progressive lens meets with just as much success as slab off on segmented multifocal lenses. As with any

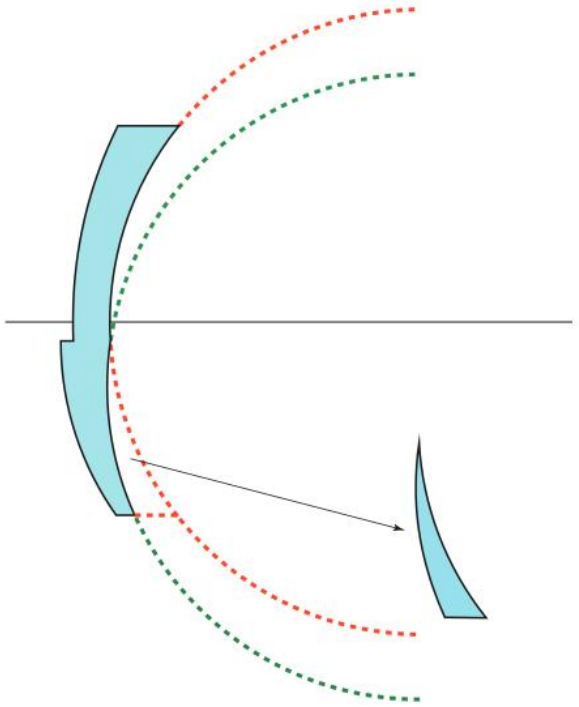


Figure 21.9 In this slab-off lens, the distance (upper) portion of the lens is surfaced with a curve shown by using red dots. The center of curvature of the red arc will be located on the optical axis line. The lower portion of the lens is surfaced with a curve shown by using green dots. Notice that both upper and lower (red and green) arcs have the same radius of curvature. The difference is that the center of curvature of the green arc will be lower than that of the red arc. It will be below the optic axis line. This is why an alternate name for applying slab off is *bicentric grinding*. The prefix "*bi*" means two. There are two different centers of curvature even though the radii of curvature of the two arcs are the same. The lower center of curvature of the green arc causes a base-up prismatic effect in the lower portion of the lens. The surfacing done by the green arc removes lens material in the lower portion of the lens. The material removed has the shape of base-down prism. This is shown by the blue wedge that, before being removed, would have been bordered by the wedge of red dots. Removing base down has the effect of adding base up.

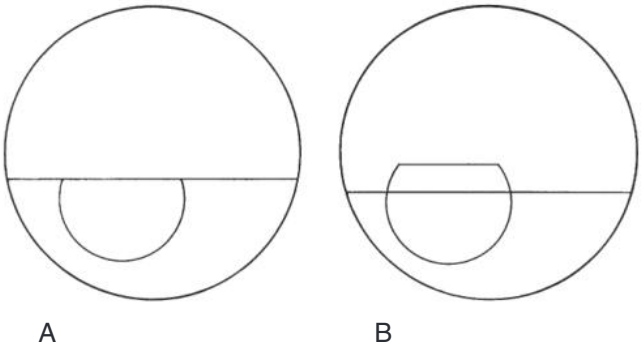


Figure 21.10 Slab-off prism produces a thin line partially concealed by a flat-top seg. The wider the seg is, the more inconspicuous the line will be. **A,** A bifocal lens is shown. **B** shows the correct position for slab-off prism on a flat-top trifocal lens. The procedure for a trifocal bicentric grind is done from the back in a manner similar to that shown in Figure 21.11 for the plastic lens.

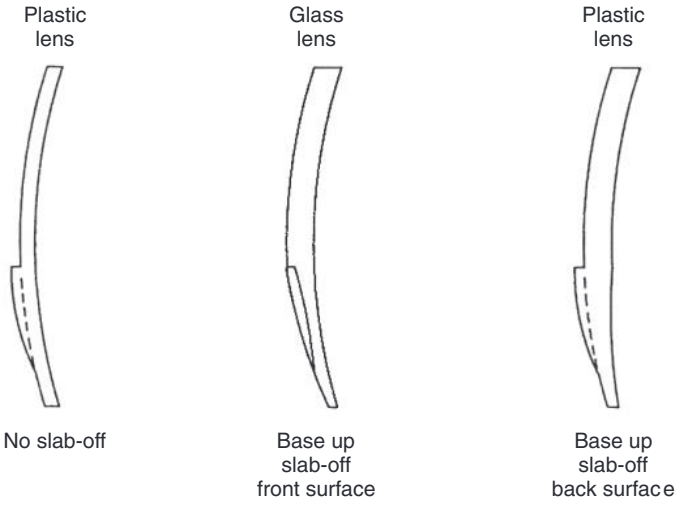


Figure 21.11 Slab-off lenses of plano distance power are compared with one another and with a nonslab-off plastic lens. These cross-sectional drawings show the location of the slab-off grind and how that grind affects lens thickness for a plano lens.

slab-off correction, the critical aspect is selection of the candidate and as expected "presbyopia in the presence of anisometropia of greater than 2 to 3 D in the vertical meridian should trigger slab-off consideration. However, we don't consider slab off if the patient is already a successful multifocal wearer with no near-vision complaints. We also tend to avoid slab off in the first-time multifocal wearer, because many anisometropic patients are able to successfully manage the vertical prism. We prefer to use slab off only when it becomes necessary. These patients also often benefit from aniseikonic lens designs—at least equal center thickness and base curves."[10]

The specifics of corrections for vertical imbalance with progressive addition lenses are covered later in this chapter.

Slab-Off Verification

The amount of slab-off prism present may be verified by comparing the seg areas of the slab-off lens with its partner lens through a lensmeter.

It is possible to request a specific amount of slab-off prism to the optical laboratory. It is also possible to ask the optical laboratory to create a lens pair with slab off that yields a zero vertical differential prismatic effect at a specific reading level. If this is requested, then the amount of vertical prism at this specific level should be the same for both right and left lenses. When the glasses are in the lensmeter centered for near at this specified level, both lenses will show the same amount of vertical prism.

Dissimilar Segs

One possible method of compensating for vertical imbalance in the reading area makes use of the prismatic effect induced by the segment of a bifocal lens.

If the bifocal wearer looks through his or her bifocal segment, unless he or she is looking through the segment's optical center, the segment (itself a miniature lens) will produce a prismatic effect. This prismatic effect is separate from that produced by the distance lens.

When both right and left bifocal segs are of the same type, are set at the same heights, and have the same power addition, the vertical prismatic effects produced by each segment will be the same for both right and left eyes.

However, if you recall from the discussion of image jump in Chapter 19, different segment types have their segment optical centers located different distances from the top of the segment. For example, when a wearer's eye reaches the top of a flat-top 45 or a Franklin-style segment, no prism is induced because the eye will be at the optical

center of the near segment. In contrast, if the wearer's eye reaches the top of a round 22, a significant amount of base-down prism will be experienced because the eye will be 11 mm above the optical center of that segment. By deliberately choosing a different segment type for each eye, it is possible to induce different amounts of vertical prism at near for each eye to counteract some of the vertical imbalance created by distance lenses with powers that are unequal.

Despite the above creative solution to the patient's problem, dissimilar segments are rarely used. They are not recommended for correcting high amounts of vertical imbalance, and the dissimilarity can also provide poor cosmesis. In addition, there are also areas in the field of view of the lens where the wearer is looking through the distance portion of one lens and the seg portion of the other. Therefore, slab-off prism is typically the preferred method of correcting vertical imbalance in spectacles compared with using dissimilar segments.

DETERMINING THE CORRECT AMOUNT OF COMPENSATION FOR VERTICAL IMBALANCE

The steps needed for determining the needed amount of vertical imbalance when using segmented multifocals are as follows:

1. Select an appropriate frame and measure for bifocal height.
2. Determine the vertical location within the segment where reading will take place. That level is called the *reading level*. (The terms *reading level* and *reading depth* are used synonymously.)
3. Determine the prism amount that is to be used to correct the imbalance.

Bifocal height is determined as was explained in Chapter 5.

Determining the Reading Level

To determine the reading level, consider how far below the seg line most near work will be viewed. In other words estimate how far below the seg line the reading level will be. This estimation allows a certain amount of flexibility. The closer to the line that the reading level is estimated to be, the more likely the imbalance will be "undercorrected." Thus, the person doing the calculation can choose to undercorrect the imbalance a certain amount by choosing a higher reading level. In most instances, reading level will be 3 to 5 mm below the bifocal segment line. The reading level will be the seg drop plus the estimated distance that the reading level is below the seg line.

Example 21.4

The MRPs for a pair of flat-top bifocal lenses are both 23 mm high. The lenses are measured for placement at a seg height of 18 mm. What will the reading depth be?

Solution

An estimate of the reading level position is made for 3 mm below the seg line. This allows the distance between the MRP and reading level to be calculated. First, the position of the seg line is determined.

$$\begin{array}{l} 23\,\text{mm (position of MRP)} \\ -18\,\text{mm (seg height)} \\ \hline = 5\,\text{mm (seg drop below MRP)} \end{array}$$

To find the reading depth, 3 mm is added to this value so that the eyes are far enough into the seg area to allow for reading.

$$\begin{array}{l} 5\,\text{mm (set drop below MRP)} \\ +3\,\text{mm} \\ \hline = 8\,\text{mm (reading depth)} \end{array}$$

METHODS FOR DETERMINING THE PRISM CORRECTION NEEDED

How the Prescriber Determines the Needed Amount of Imbalance Correction

Correcting for a vertical imbalance at near may not necessitate using the full amount of calculated compensation. (How the amount of vertical imbalance is calculated is covered later in this chapter in the section titled Correcting the Full Imbalance by Calculations.) Some individuals with a longstanding vertical imbalance become acclimated to it and through continuous use are able to overcome some of the prismatic effect by vertically diverging the eyes somewhat when reading or performing near tasks. Thus, many spectacle lens wearers are able to compensate partially for an imbalance themselves. For example, a person may show a need for 2.00Δ of slab-off prism when actual calculations indicate a need for 3.00Δ. It is possible to test and see how much imbalance is required. This is most easily done if the person is wearing glasses that contain a current, valid distance prescription.

With the individual wearing the correct distance prescription, place tape over the upper portions of the lenses at the actual or theoretical segment line location. This forces the wearer to look below the tape and through the lower area of the lenses at the level where he or she will be reading. A fixation disparity testing unit is held in the reading position and Polaroid filters placed over the glasses. Hold a hand-held vertical prism bar with prisms of increasing power over one of the wearer's eyes. (If a prism bar is not available, loose trial prism lenses may be used.) Incrementally increase the prism amount by moving the prism bar until the fixation disparity target shows proper alignment. This is the correct amount of slab-off prism needed.

If a fixation disparity testing unit is not available, it is possible to position a pen light at the reading level and place a red Maddox rod over one eye. Incrementally increase the prism over one eye with the prism bar until the red line intersects with the white light. This method may yield a larger amount of vertical prism than the fixation disparity method. When imbalance is determined using methods such as these, the prism amount becomes a part of the prescription.

Sometimes, a prescription simply indicates the need for slab off but does not state the amount, leaving it to the dispenser or laboratory to calculate. In many instances, even when the need for slab off exists, it is not part of the prescription. This does not preclude the dispenser from incorporating slab off in the wearer's spectacles, however, since vertical imbalance is a spectacle-lens-induced problem.

How to Use a Lensmeter to Determine the Amount of Imbalance

If the wearer's distance prescription has not changed, the amount of imbalance may be determined as follows:

1. Spot the MRPs of the lenses.
2. Having predetermined the reading position, locate the reading centers. This is done by measuring down from the MRPs to the reading level and in by the amount seg inset.
3. Spot the newly located reading centers. (These will correspond to the wearer's near interpupillary distance [near PD] at the reading level).
4. Center one reading center before the lensmeter aperture and read the amount of vertical prism present. Without moving the lensmeter table up or down, slide the glasses over so the second reading center is in front of the lensmeter aperture and measure the vertical prismatic amount at this point.
5. The vertical prism difference between these two vertical prism readings is the full amount of vertical prism imbalance experienced by the wearer.

If the distance prescription has changed, the old glasses cannot be used to measure vertical imbalance.

The Role of the Optical Laboratory in Determining Vertical Imbalance

If asked, the optical laboratory will determine the amount of slab-off prism needed by calculation. The chief advantage a laboratory may have is the possible availability of better computer software containing the most appropriate formulae for full correction. The dispenser may choose to specify the position of the reading level. If this is not done, the laboratory will make that choice themselves. The advantage for the dispenser when choosing the reading level is this. Since the laboratory will compute the *full* amount of imbalance, the dispenser-selected reading level is where there should be no vertical imbalance present during verification.

CORRECTING THE FULL IMBALANCE BY CALCULATIONS

If the full correction for vertical imbalance is indicated, this may be calculated. There are several methods of calculation that may be used as will be described in the following sections. The methods do not always result in exactly the same answers. As with any decentration problem, difficulty in calculation increases with the complexity of the prescription—the easiest being spheres and the most difficult, sphero-cylinder combinations. The steps normally used to find the amount of vertical imbalance using Prentice's rule are shown in Box 21.4.

Using Prentice's Rule to Calculate Vertical Imbalance for Spheres

The traditional methods for calculating vertical imbalance use Prentice's rule. Here, this traditional method will be explained, starting with an example of a prescription for spherical lenses.

Example 21.5

Suppose vertical imbalance at near is to be corrected for the following prescription:

O.D. +3.00 D sphere
O.S. +0.50 D sphere
Add: +2.00 D
Frame B dimension = 46 mm
Seg height = 19 mm
Reading level is 4 mm below the seg line.

What is the vertical imbalance at the reading level?

Solution

Begin by finding the reading level. In calculating imbalance, it is helpful to visualize the situation described. Because the B dimension is 46 mm,

$$\text{Seg drop} = \frac{B}{2} - \text{Seg height}$$
$$= \frac{46}{2} - 19$$
$$= 23 - 19$$
$$= 4\,\text{mm}$$

Because the reading level is 4 mm below the seg line, it will be 8 mm below the distance OCs. (This is shown in Figure 21.12.)

Use Prentice's rule to determine the vertical prismatic effect at the reading level. In the example problem, the reading level is 8 mm below the OC, so the vertical prismatic effect for the right eye is

$$\Delta_V = cF$$
$$= 0.8 \times (3.00)$$
$$= 2.40\Delta \text{ base up}$$

The base direction is up since the lens is plus. (Since we are only concerned with vertical prismatic imbalance, the horizontal prismatic effect is not needed and does not need to be calculated.)

The vertical prismatic effect at the left reading center is calculated in the same manner as for the right.

$$\Delta_V = cF$$
$$= 0.8 \times (0.50)$$
$$= 0.40\Delta \text{ base up}$$

Therefore the vertical imbalance is the difference between the left and right vertical components at the reading level.

$$\begin{array}{r} 2.40\Delta \text{ base up O.D.} \\ -0.40\Delta \text{ base up O.S.} \\ \hline = 2.00\Delta \text{ base up O.D.} \end{array}$$

The full correction for vertical imbalance must counteract 2.00Δ base up before the right eye at near. This is done by placing 2.00Δ of base-up prism before the left eye at near.

The slab-off correction is placed before the most minus or least plus lens. In this case, the least plus lens is the left lens.

BOX 21.4 Steps for Finding Vertical Imbalance Using Prentice's Rule

1. Find the reading level. The reading level is the seg drop plus the distance from the segment top to the level at which the wearer is expected to read (usually 3 to 5 mm below the bifocal segment).
2. Find the power of each lens in the 90-degree meridian.
3. Find the prismatic effect at the reading depth of each lens.
4. Find the prismatic difference (vertical imbalance) between the right and left lenses.
5. When using slab off, determine which lens will receive the imbalance correction.

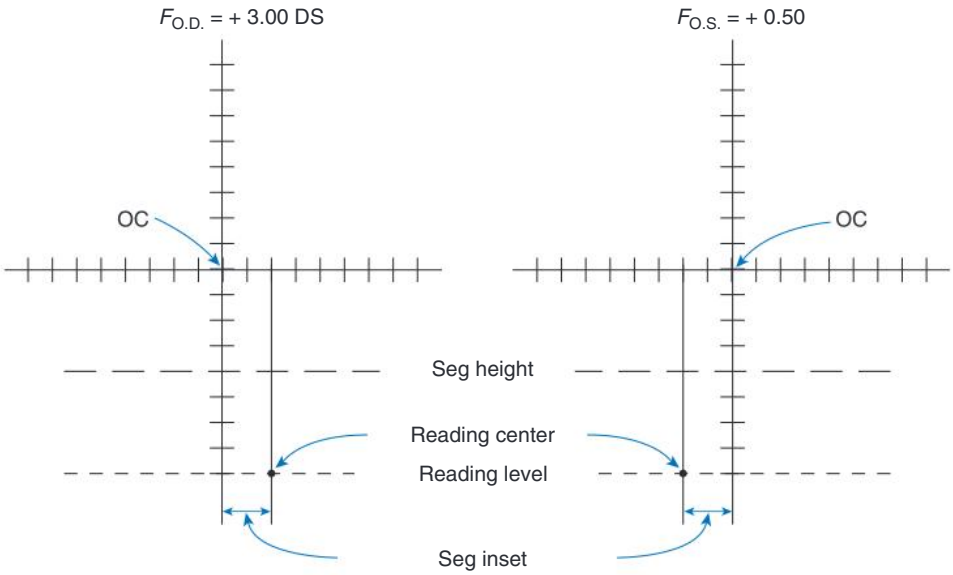


Figure 21.12 Reading center location is specified from two dimensions. The lateral position is dictated by the near interpupillary distance, which determines seg inset, and the vertical position is ascertained by reading level.

Using Prentice's Rule to Calculate Vertical Imbalance for Spherocylinders

Spherocylinders at 90 or 180 Degrees

Calculation of vertical imbalance at near for spherocylinders is fairly straightforward when the cylinder axes are at 90 or 180 degrees.

Example 21.6

Calculate the imbalance for the following prescription:

O.D. + 4.00 − 0.50 × 180
O.S. + 2.00 − 1.25 × 180
Add : + 2.00 D
Seg drop = 4 mm
Reading level is 5 mm below the segment line.

Solution

1. First we find the distance from the optical center of the lens to the reading level. This is the seg drop plus the distance from the segment line to the reading level. In this case, it would be

$$\text{Reading depth} = 4\text{mm} + 5\text{mm} = 9\text{mm}$$

2. Next, find the power of each lens in the 90-degree meridian. This can be done by placing the prescription on power crosses as shown in Figure 21.13. For the right lens, the power in the 90-degree meridian is +3.50 D. For the left lens, the power in the 90-degree meridian is +0.75 D.
3. Now, we use Prentice's rule to find the vertical prismatic effect at the reading level. For the right lens this is

$$\Delta = cF = 0.90 \times 3.50 = 3.15\Delta \text{ base up}$$

Since the lens is a plus lens and we are looking below the optical center, the base direction is base up. The prismatic effect is 3.15Δ base up.

For the left lens

$$\Delta = cF = 0.90 \times 0.75 = 0.675\Delta \text{ base up}$$

The prismatic effect is 0.675Δ base up.

4. Since both lenses have a base-up prismatic effect, the prismatic difference is found by subtracting the two numbers.

$$3.15\Delta \text{ base up} - 0.675\Delta \text{ base up} = 2.475\Delta \text{ base up}$$

The *imbalance* is rounded to 2.50Δ base up and is written as 2.50Δ base up O.D. (It could also be expressed as 2.50Δ base down O.S.) *Do not confuse the imbalance with the correction!*

The slab-off *correction* used will be done in the traditional manner and will be base up. Therefore, it will be placed on the eye that has the most minus or least plus refractive correcting power in the 90-degree meridian. For this prescription, the slab off goes on the left lens, which is the least plus.

Example 21.7

Calculate the imbalance for the following prescription:

O.D. − 4.00 − 1.00 × 180
O.S. + 1.00 − 0.50 × 180
Add : + 1.50 D
Frame B dimension = 34 mm
Seg height = 14 mm

Reading level is determined to be 4 mm below the top of the bifocal line.

Solution

First, find the reading level. This is done by finding the seg drop and adding it to the distance from the segment line down to the reading level. Segment drop is

Figure 21.13 To calculate vertical prismatic effect for spherocylinder lenses with axes at 90 or 180 degrees, it helps to place the lens powers on a power cross. The power in the 90-degree meridian then becomes easier to see.

$$\text{Seg drop} = \frac{B}{2} - \text{Seg height}$$
$$= \frac{34}{2} - 14$$
$$= 17 - 14$$
$$= 3\text{mm}$$

The segment drop of 3 mm is added to the 4 mm distance to the reading level, which totals 7 mm.

Next, we find the power of each lens in the 90-degree meridian. For the right lens, the power in the 90-degree meridian is −5.00 D. For the left lens, this will be +0.50 D.

For the right lens, the vertical prismatic effect for a distance 7 mm (0.7 cm) below the distance OC is found by using Prentice's rule.

$$\Delta = cF$$
$$= 0.7 \times 5.00$$
$$= 3.5\Delta \text{ base down}$$

The direction is base down because the lens is minus in the 90-degree meridian and we are looking below the distance OC.

For the left lens, the prismatic effect will be

$$\Delta = cF$$
$$= 0.7 \times 0.50$$
$$= 0.35\Delta \text{ base up}$$

The prism direction is base up because we are looking through the lower half of the lens and the lens is plus in power in the 90-degree meridian. To find the amount of imbalance, we will need to add the two prism amounts. This is because one base direction is base down and the other base up. The total amount of *imbalance* can be expressed as either

3.85Δ base down, right eye, or
3.85Δ base up, left eye

The amount of *correction* must be an equal and opposite amount. This amount is 3.85Δ of base-up prism placed on the right eye The right eye has the most minus power in the 90-degree meridian.

Using the Cosine-Squared Method to Find Vertical Imbalance With Oblique Cylinders

The cosine-squared method is a shortcut method for finding vertical imbalance when a prescription includes oblique cylinder. Results obtained using this method are not exact but reasonably close and considerably easier. This method allows one to find a total lens power for the 90-degree meridian following these steps:

1. Find the "power" of the oblique cylinder in the 90-degree meridian of the right lens using the formula:

$$F_{90\text{cyl}} = F_{\text{cyl}} \cos^2\theta$$

where

$F_{90\ \text{cyl}}$ = power of the cylinder in the 90-degree meridian
F_{cyl} = power of the cylinder
θ = axis of the cylinder

2. Add the power of the cylinder in the 90-degree meridian for the right lens to the power of the sphere for the right lens ($F_{90\ \text{cyl}} + F_{\text{sphere}}$).
3. Repeat steps 1 and 2 for the left lens.
4. Either (A) multiply each power by the reading depth distance and then find the prismatic difference between the two (a longer method) or (B) find the power difference between the right and left lenses and then multiply this difference by the reading depth distance (a shorter method). This shorter method of finding the difference in vertical meridian powers may be used for any lens pair, including the previously given examples.

Example 21.8

Calculate the vertical imbalance for the following prescription using the cosine-squared method:

O.D. + 3.00 + 2.50 × 030
O.S. + 0.50 + 1.00 × 135
Add : + 2.00
The flat-top bifocal segment has a seg drop of 3 mm.
The reading level is 5 mm below the segment top.

Solution

1. To find the power of the cylinder in the 90-degree meridian, use

$$F_{90\text{cyl}} = F_{\text{cyl}} \cos^2\theta$$
$$= (+2.50)\cos^2 30$$
$$= (+2.50)(0.75)$$
$$= +1.875\text{D}$$

2. Adding the power of the cylinder in the 90-degree meridian (+1.875 D) to the sphere power (+3.00) gives:

$$+3.00 + 1.875 = +4.875\,\text{D}$$

3. Repeating for the left lens results in

$$\begin{aligned} F_{90\text{cyl}} &= F_{\text{cyl}} \cos^2\theta \\ &= (+1.00)\cos^2 135 \\ &= (+100)(0.50) \\ &= +1.50\,\text{D} \end{aligned}$$

for the cylinder power in the 90-degree meridian.

$$\begin{aligned} \text{Total lens power in the 90-degree meridian} &= (F_{90\text{cyl}} + F_{\text{sphere}}) \\ &= (+0.50) + (+0.50) \\ &= +1.00\,\text{D} \end{aligned}$$

4. For this step, proceed in one of two ways. The first way, though somewhat longer, is that used in earlier examples.
   A. Multiply each 90-degree lens power by the reading depth distance in centimeters. We know the lens power in the 90-degree meridian but not the reading depth. The reading depth is 5 mm below the segment line, and the segment line has a drop of 3 mm. This places the reading level 8 mm (0.8 cm) below the distance OC. Now we can find vertical prismatic effect.

For the right lens, this is

$$(4.875)(0.8) = 3.9\Delta \text{ base up}$$

For the left lens, this is

$$(1.00)(0.8) = 0.8\Delta \text{ base up}$$

The total vertical imbalance at the near point is the difference between these two vertical prismatic effects.

$$\begin{aligned} &3.90\Delta \text{ base up O.D.} \\ &-0.80\Delta \text{ base up O.S.} \\ &= 3.10\Delta \text{ base up O.D.} \end{aligned}$$

To shorten the process, we use the second option:

B. Find the difference between right and left lens powers. In the 90-degree meridians, these differences are

$$(+4.875) - (+1.00) = +3.875\,\text{D}$$

Next, multiply the power difference by the reading depth in centimeters.

$$(3.875)(0.8) = 3.10\Delta \text{ base up O.D.}$$

Both of these ways of finding the imbalance result in the same amount of vertical imbalance.

(For a summary of how to calculate vertical imbalance using the cosine-squared method, see Box 21.5.)

BOX 21.5 Calculating Vertical Imbalance Using the Cosine-Squared Method

1. Find the reading depth.

$$\text{Reading depth} = \text{Seg drop} + 5\,\text{mm (usually)}$$

2. Find the "power" of the oblique cylinder in the 90-degree meridian of the right lens using the formula

$$F_{90\text{cyl}} = F_{\text{cyl}} \cos^2\theta$$

where
$F_{90\text{cyl}}$ = power of the cyl in the 90-degree meridian
F_{cyl} = power of the cylinder
θ = axis of the cylinder

3. Add the power of the cylinder in the 90-degree meridian for the right lens to the power of the sphere for the right lens.

$$(F_{90\text{cyl}} + F_{\text{sphere}})$$

4. Repeat steps 2 and 3 for the left lens.
5. Find the power differences between right and left lenses, and then, multiply this difference by the reading-depth distance.

(Note: You may recognize the cosine-squared formula described here as being an alternative to the sine-squared formula that was discussed at the end of Chapter 13. The sine-squared formula is also capable of calculating the "power" of an oblique cylinder in 90-degree meridian as long as the value for θ is the difference between the cylinder axis and the 90-degree meridian. The cosine-squared method uses the difference between the axis of the cylinder and the 180-degree meridian, which will be the same degree measurement as the axis of the cylinder itself!)

FITTING, MEASURING, AND CALCULATING FOR SLAB OFF WITH PROGRESSIVE ADD LENSES

Reducing the Needed Amount of Correcting Prism

One possibility for lessening the amount of correcting prism for vertical imbalance is to choose a frame with a smaller B dimension. Then, use a short corridor progressive so that there is less distance down into the lens for near viewing. It is also possible to order a short corridor progressive lens, but use it in a frame with a deeper B dimension. This will still allow a reduced amount of vertical imbalance correcting prism as was accomplished by choosing a frame with a shorter B dimension.

An alternative method of reducing the amount of correcting prism needed is to use a degressive power progressive lens. This lens is made for just intermediate and near vision. (See Chapter 20, *Progressive Addition Lenses* in the section on *Degressive Power Lenses.*) In this way, the near viewing area will be closer to the center of the lens. With a higher near viewing area, less slab off will be needed. In many cases, a slab-off correction may not be needed at all.

Calculating Vertical Imbalance for Progressive Addition Lenses

When calculating for the full amount of vertical imbalance prism using Prentice's rule, use the distance from the prism reference point (PRP) to the reading level. The reading level is usually considered to be at the location of the near reference point (NRP). Do NOT calculate the distance to the reading level by starting from the fitting cross!

Example 21.9

A patient has the following prescription:

R : −2.00 DS
L : −5.00 DS
Add : +2.25 D
Frame B = 30 mm
Fitting cross height = 21 mm

For this lens, the distance from the fitting cross to the PRP is 4 mm. (For specific lenses, see the manufacturer's centration chart or the Vision Council's Progressive Identifier available on their web site at epic.thevisioncouncil.org as an Electronic Progressive Identifier Catalog. The centration chart allows a better visualization of lens characteristics.)

This particular progressive addition lens lists a minimum fitting height of 16 mm. Lens manufacturers usually list the minimum fitting height as the distance from the fitting cross to the NRP. (If the lens is fit at its minimum fitting height, this usually means that the center of the NRP is right at the bottom of the edged lens!)

For this problem, how much vertical imbalance would you need to fully correct for this prescription in this frame?

Solution

To find the distance from the PRP to the center of the NRP, we need to know the corridor length. In this example, we are given the minimum fitting height of 16 mm. We are also given the distance from the fitting cross to the PRP—4 mm. The progressive corridor starts at the PRP. Thus, the distance from the PRP to the NRP is $16 - 4 = 12$ mm (Figure 21.14).

Ignoring yoked base-down prism for thinning the lens, for the right lens the prismatic effect at the center of the MRP is

$$\begin{aligned}\Delta &= cF\\ &= (1.2)(2)\\ &= 2.40\Delta \text{ base down}\end{aligned}$$

For the left lens the prismatic effect at the center of the NRP is

$$\begin{aligned}\Delta &= cF\\ &= (1.2)(5)\\ &= 6.00\Delta \text{ base down}\end{aligned}$$

The imbalance is $6.00 - 2.40 = 3.60\Delta$ base up right eye or 3.60Δ base down left eye. The correction will be equal and opposite to the imbalance. For a traditional slab off this would be 3.60Δ base up on the left eye.

Notice that in figuring for progressives we don't have to use either the B dimension or the fitting cross height to calculate the amount of imbalance. However, we will need the B dimension and the fitting cross height to specify where we want the slab line to be located.

Where Should the Slab Line Be Positioned?

There are many positions that have been recommended for the slab line, from a low of just above the near reference area to right in the middle of the lens. Although all of these positions may be feasible, keep in mind that, for trifocal lenses, the position of the slab line is at the bottom of the intermediate viewing area on the second multifocal line. This position avoids overcorrecting vertical imbalance for intermediate viewing.

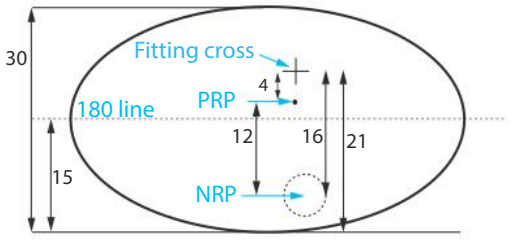


Figure 21.14 Here are the locations of the fitting cross, prism reference point (*PRP*), and near reference point (*NRP*) for this particular frame/lens combination.

Option 1: Position the Slab Line High

The argument for the higher slab line location is that it will look better, will allow use when the wearer is doing near work but is not looking fully downward, and perhaps will be less noticeable to the wearer. *The arguments against* the higher slab line location is that the wearer is being overcorrected for vertical imbalance for the intermediate viewing area, and the slab line may interfere with vision in some situations. Looking directly through the slab line can produce monocular diplopia (double vision seen with one eye).

Two possible high slab height options that have been advocated are

1. Along the 180-degree line, meaning the line would be centered vertically in the edged lens, and
2. At the level of the PRP or 0.5 mm below it. (Many labs use this as their default option.)[9]

Option 2: Position the Slab Line Low

The argument for the lower slab line location is that it keeps the intermediate viewing area from being overcorrected. *The argument against* the lower slab line is that it may interfere with an often-used viewing area. Many people drop their eyes down to the point on the lens were the add reaches 85% and use that area for casual near viewing. The recommended position for the low line position is slightly above the Near Verification Circle.

Option 3: Drop the Slab Line Height From the 180-Degree Line

At least one slab-off specialty laboratory does the following[11,12]:

As a default for most frames, the slab line is positioned 4 mm below the 180-degree line of the frame.

If the frame B is small, the height is changed to 2 or 3 mm below the 180-degree line.

This option is close to that of Option 1, Position the Slab Line High.

Option 4: Position the Slab Line Where Imbalance Reaches 1 Prism Diopter

This option uses the premise that for vertical imbalance amounts of prism below 1Δ, the wearer is normally able to compensate and would therefore not be considered undercorrected when looking above the slab line. The point at which this 1Δ amount is reached is used as the position for the location of the slab line. This level is found by using Prentice's rule ($\Delta = cF$), where

Δ = is taken to be 1Δ,

c = the unknown distance from the PRP to the slab line, and

F = the dioptric difference between the powers in the 90-degree meridians for left and right lenses.

How this works will be shown in Example 21.9 Continued.

Example 21.9 Continued

In the first part of Example 21.9 started previously, the full amount of slab-off correction was calculated. Now the problem continues by asking where the slab line should be positioned for each of the options listed previously.

Solution

Here are the possible slab line height answers we could get for each of the above listed options.

Option 1: Position the Slab-Line High

Here are two possibilities:

1. Place the slab line on the 180-degree line. This would position the line at a height of 15 mm (30/2 = 15). (A slab-off line should not be placed above the level of the PRP. This 15-mm level is not above the PRP.)
2. Place the slab line at a level 0.5 mm below the PRP. For this particular lens, the PRP height is

$$\begin{aligned}\text{PRP height} &= \text{Fitting cross height} - 4\,\text{mm}\\ &= 21 - 4\\ &= 17\,\text{mm}\end{aligned}$$

Now, we subtract 0.5 mm from 17 to get a 16.5-mm slab-line height (Figure 21.15, *A*).

Option 2: Position the Slab Line Low

Here, the slab line is placed slightly above the near verification circle.

To place the line slightly above the near verification circle, we need to know where the top of the near verification circle is located. For this particular progressive addition lens, the distance from the fitting cross to the NRP is 16 mm. The NRP verification circle is about 6 mm in diameter. This would place the top of the near verification circle 3 mm above the NRP. Therefore, the distance from the fitting cross to the top of the near verification circle is

$$16 - 3 = 13\,\text{mm}$$

If the fitting cross height is 21 mm, then the top of the near verification circle would be at a level of

$$21 - 13 = 8\,\text{mm}$$

Slightly above is not an exact term. Since 8 mm is *very* low, one would expect that *slightly above* could increase up to a level of perhaps 12 mm (see Figure 21.15, *B*).

Option 3: Drop the Slab Line Height From the 180-Degree Line

This method would place the slab line either 4 mm below the 180-degree line for most frames or 2 to 3 mm below for those frames having narrow B dimensions.

The B dimension of this frame is 30 mm. A 30 -mm B dimension could be considered as having a narrower B dimension. The 180-degree line is at a height of 30/2 = 15 mm. So, although the slab line might be positioned at 15 − 4 = 11 mm for regular frames, here, we might place the line 2 or 3 mm below the 180-degree line. This would be at a height of 12 or 13 mm. For this particular lens design and frame choice, a 12- or 13- mm choice would likely give good results (see Figure 21.15, *C*).

Option 4: Position the Line at the 1.00Δ Break Point

In this example, the difference in 90-degree meridian power is the difference between − 5.00 and − 2.00 D, which is 3.00 D. The formula for Prentice's rule is

$$\Delta = cF$$

Δ = is taken to be 1Δ,
c = the unknown distance from the PRP to the slab line, and
F = the dioptric difference between the powers in the 90-degree meridians for left and right lenses.

Because we are looking for the unknown distance, *c*, Prentice's rule is transposed to

$$c = \frac{\Delta}{F}$$

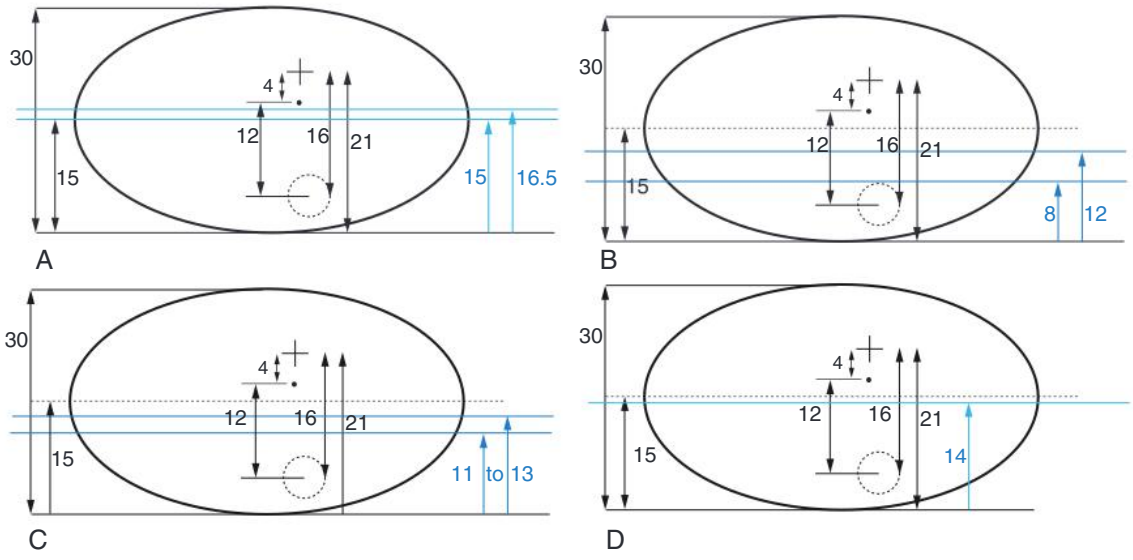


Figure 21.15 **A,** Option 1 for positioning the slab line on a progressive lens is to position the slab line high. Two possibilities are to either place the line on the 180-degree line or place the line 0.5 mm below the prism reference point (PRP). In this example , positioning the slab line high would place it at a height of from 15 to 16.5 mm. **B,** Option 2 is to position the slab line low—slightly above the near reference circle. In this case, the line height at 8 mm would not give enough reading area. Therefore, raising it up to 12 mm would be more reasonable. **C,** Option 3 (Drop the line from the 180-degree line). In this option, the slab line is dropped either 4 mm below the 180-degree line for most frames or 2 to 3 mm below for those frames having narrow B dimensions. In this example, if the frame were of regular depth, the slab line would be dropped 4 mm down to an 11- mm height. However, because this frame has a narrow B dimension, the more appropriate height using this option would be 12 or 13 mm. **D,** Option 4 is to position the slab line at the 1.00Δ break point. In this example prescription, the 1.00Δ break point is 3 mm below the PRP, which results in a 14 -mm high slab-off line.

Therefore,

$$c = \frac{1}{3.00}$$
$$= 0.33\,\text{cm or } 3.3\,\text{mm}$$

In other words, the slab line would be positioned 3 mm below the PRP. Since the PRP height is at 17 mm as calculated earlier, the slab-line height would be

$$\text{Slab} - \text{line height} = 17 - 3 = 14\,\text{mm}$$

(see Figure 21.15, *D*).

We can see that there are several variations in possible locations for the slab-off line. Frame dimensions and style along with the professional judgment of the prescriber or dispenser should drive the final decision.

Correcting Vertical Imbalance for Both Distance and Near Viewing

Just as there is vertical imbalance in the lower half of an anisometropic lens pair, so also is there vertical imbalance in the upper half. Because the distance from the MRP (PRP for progressives) to where the eye views objects in the distance is small, vertical imbalance for distance vision is normally not a problem. If the anisometropia is large and the wearer is sensitive to vertical imbalance, it is possible to correct vertical imbalance for both distance and near viewing points. How this is done is explained in Appendix C at the back of the book.

Remole's Method

In a series of articles,[13–17] Arnulf Remole exposes some deficiencies in the traditional methods for calculating vertical imbalance. Remole points out a basic problem with using Prentice's rule. This problem stems back to Prentice's original supposition. Prentice presented his rule in "the context of a single, hypothetically thin lens."[18] His rule works correctly when used in context. However, prismatic effect at a given point on a lens is also influenced by lens thickness and base curve.

The second problem has to do with the amount each eye turns downward. To find vertical imbalance in the traditional manner, we must determine a reading level. To calculate imbalance, we assume that both eyes turn downward equally, looking through a reading level that is the same distance below the optic axes for both right and left eyes. Yet, we know that unequal vertical prism is induced by unequal left and right lens powers. This causes the two eyes to turn downward by different amounts. This will place them at slightly different distances from their starting points and not at the same reading level.

Remole presents an alternate method for finding prismatic effect that takes lens thickness, base curve, and unequal vertical turning of left and right eyes into consideration. It shows how aniseikonia and vertical imbalance are related and how correcting for aniseikonia has a direct influence on the amount of vertical imbalance correction that may be required.

Prismatic Effect and Magnification Are Related

Magnification is the result of a changing prismatic effect across a lens. The equation for spectacle magnification is employed when calculating magnification with aniseikonia. This equation takes both base curve and lens thickness into account. Changing either base curve or lens thickness causes a change in magnification. Remole uses spectacle magnification to more accurately find prismatic effect at a given point on a lens.

Normally, the entrance pupil of the eye is used when calculating spectacle magnification for aniseikonia purposes. Here is the conventional formula as previously described when discussing aniseikonia.

$$\text{SM} = \left(\frac{1}{1 - \frac{t}{n}F_1}\right)\left(\frac{1}{1 - dF_v'}\right)$$
$$= (S)(P_{\text{stat}})$$

where

SM = static spectacle magnification
t = center thickness
F_1 = front surface lens power
n = refractive index
d = distance from the back surface of the lens to the entrance pupil of the eye (usually vertex distance plus 3 mm)
F_v = back vertex lens power
S = shape factor
P_{stat} = static power factor

Remole uses P_{stat} to point out that this is the power factor for an eye that is not moving. However, when calculating spectacle magnification when the eye is moving, Remole maintains that the more logical point of reference is the center of rotation of the eye. "Because the entrance pupils of the eye move as the eye rotates, they can't be used as reference points. Instead, the center of rotation must be used."[13] This changes the formula for the eye when it is no longer in the straight-ahead position. The formula then becomes a "dynamic spectacle magnification formula" where G stands for dynamic spectacle magnification. Therefore, the formula reads:

$$G = \left(\frac{1}{1 - \frac{t}{n}F_1}\right)\left(\frac{1}{1 - sF_v'}\right)$$
$$= (S)(P_{\text{dyn}})$$

There are only two differences in the static and dynamic formulae. The first difference is that dynamic formula *d* now becomes *s*, where *s* is the distance from the back surface of the lens to the center of rotation of the eye. The second difference is that P_{stat} that was the static power factor becomes P_{dyn}, the dynamic power factor.

So "in dynamic spectacle magnification, primary image sizes are determined with reference to the centers of rotation rather than the entrance pupils."[13]

Comparing Results: Remole's Method Versus Prentice's Rule

Results obtained using Remole's method will not yield the same results as found using Prentice's rule. Because Remole's method takes both lens thickness and base curve into consideration, it would be expected to give more accurate results. So how do the two compare?

Fortunately, "The conventional application of Prentice's rule can be applied to most low and moderate anisometropic minus lens corrections without producing clinically significant errors."[13] However, "The differential prismatic effects found with minus lenses by using the exact formula are smaller than the estimate made by Prentice's rule, whereas with plus lenses, the prismatic effects are larger."[13] In fact, "The conventional application of Prentice's rule to anisometropic plus lens corrections will often result in large errors."[13]

Simply put, "… the textbook application of Prentice's rule will underestimate the differential prismatic effect for plus lens corrections and overestimate the effect for minus lens corrections."[13] In other words *when calculating using Prentice's rule*, consider doing the following:

- For plus lenses, your answer will be too low. If you want *full* correction, increase it some.
- For minus lenses, your answer will be a little bit high. Consider reducing the amount you found but not by much.

Reducing Aniseikonia Will Also Reduce Vertical Imbalance

When aniseikonia is present, one lens has a different power than the other. This means that in the periphery of the higher powered lens, there is more prismatic effect. By changing parameters such as base curve and lens thickness, magnification changes and, as we have seen in the previous section, so does prismatic effect. This means that, hypothetically, if we are able to make right and left lenses have the same (dynamic) spectacle magnification, we will also eliminate vertical imbalance. "Furthermore, the absence of prismatic effect will apply to the entire binocular field, which presents an enormous advantage over a slab-off lens."[13]

However, as Remole himself points out, this will not usually be the case because the clinically measured amount of aniseikonia is usually less than the calculated amount. Thus, the calculated amount of aniseikonia will not be fully corrected. But it does mean that any amount of correction for aniseikonia will lessen the need for as much vertical imbalance correction.

In summary:

1. Reducing aniseikonia will reduce the amount of vertical imbalance correction needed.
2. Reducing aniseikonia may reduce the vertical imbalance a sufficient amount so that the remaining imbalance is not clinically significant enough to require correction.

DESIGNING A LENS TO CHANGE THE APPEARANCE OF A BLIND EYE

Normally, lens power is used only to correct refractive error. Prism power is used to alleviate problems with binocular vision. Yet, there is another use for power, prism, and even tint that has nothing to do with refractive error. Power, prism, and tint can also be used to improve the cosmetic appearance of a blind or prosthetic (artificial) eye.

A skilled ocularist will be able to match the color and appearance of the artificial eye's iris and sclera to that of the seeing eye, but because of a condition of the eye socket, an artificial eye may look abnormal even when eye colors are well matched. If further cosmetic surgery will not help, cosmetics may be improved with spectacle lenses. Lenses used for cosmetic purposes are not part of the prescription. They may be determined by the dispenser at the time of frame selection.

Changing the Apparent Size of the Eye

Lenses have the optical effect of magnifying if they are plus lenses or minifying if they are minus lenses. When a plus lens magnifies, it not only causes the world to look larger to the wearer, but the wearer's eyes will also look bigger to everybody else. Normally, dispensers try to reduce this effect by using aspherics to flatten and thin the lens. Yet, sometimes, it may be advantageous to make a nonseeing eye look bigger *intentionally*.

Using Spheres

If a person has lost an eye and had it replaced with a prosthetic eye, the artificial eye may match the color of the seeing eye perfectly. The artificial eye may have a sunken appearance, however, making it look smaller. To correct this effect, hold up plus trial lenses in front of the prosthetic eye until it looks closer in size to the seeing eye. When a good match is achieved, use the experimentally found power. Likewise, if the nonseeing eye looks too big, minus power can be used to make it appear smaller. Figure 21.16 shows an example of how a –6 D lens has been used in front of a prosthetic right eye to make the eye and lid aperture appear smaller, more closely matching that of the seeing left eye.

Using Cylinders

Plano cylinders may be used to change only the horizontal or only the vertical size of the eye. For instance, sometimes even when the horizontal dimension of the eye looks normal, the vertical depth of the area between the upper and lower eyelids (the palpebral fissure) of the nonseeing eye may be smaller than that of the seeing eye. To make the fissure look larger vertically, a plus cylinder axis 180 may be used. To find the correct power, hold plus cylinders up in front of the eye until the desired cosmetic effect is achieved.

Tilting the Cylinder to Change Lid Slant

In some instances the eyelids of the prosthetic eye may appear slanted. When a cylinder lens is rotated around its axis, it will cause a horizontal line to tilt. A plus cylinder will cause a straight line to tilt against the direction of rotation, whereas a minus cylinder will cause a line to tilt with the direction of rotation. When deciding whether to use plus or minus cylinder, the deciding factor is magnification.

To determine the optimal axis placement, hold the cylinder lens in front of the eye (preferably using a trial frame) and turn the axis until the slanted lids match the straight lids.[19]

Figure 21.16 In this individual, the prosthetic eye is the right eye. Without glasses, the right eye looks larger than the left eye. Here, a –6 D lens is placed over the nonseeing right eye. This makes the prosthetic eye look smaller and helps to equalize the apparent size of the two eyes. (Courtesy Laurie Pierce, Tampa, FL.)

Summary

1. The apparent overall size of the eye may be changed using plus or minus sphere lenses.
2. By using plano-cylinder lenses, the size of the eye may be increased or decreased in one meridian (the power meridian of the cylinder). The magnification in the meridian 90 degrees away (the axis meridian) will remain unaffected.
3. Rotating a plano-cylinder lens away from the horizontal or vertical meridian causes tilt. If eyelids look unnaturally tilted, place a cylinder lens in front of the nonseeing eye, and rotate the cylinder axis until the eyelids look more like the normal eye.

Using a Lens to Camouflage Scars or Deformities

Sometimes, a nonseeing eye is scarred or disfigured but not to the point where a patch would be worn. In this case, a lens should be selected that will decrease the visibility of the eye. Tinting may be applied to the lens as either a solid or a gradient tint. An antireflection coating may not be advisable. The best cosmetic result occurs when both left and right lenses are tinted equally and match one another. Keep in mind that tinting both lenses will decrease the wearer's vision at night. Therefore it is prudent to have a second nontinted pair of glasses for night activities such as driving. Cosmetic considerations should not rule over safety considerations.

Changing the Apparent Location of an Eye

Trauma causing the loss of an eye can also cause the displacement of the socket. This makes the prosthetic eye appear higher or lower than the seeing eye. If the blind or prosthetic eye is lower or higher or appears to turn inward or outward compared with the seeing eye, its apparent location may be altered by using prism.

The base direction of the prism used will always be placed in the direction that the eye is physically displaced. In other words, if the eye appears too high, use base-up prism. If the eye turns in, use base-in prism. If this is done, then to an observer, the wearer's eye will appear to be displaced toward the apex of the prism. Such prism is called *inverse prism* because it is opposite to what would normally be prescribed for a seeing eye.

Figure 21.17 **A,** The artificial eye is this person's right eye. It appears low in comparison with the left eye. **B,** An attempt has been made to cosmetically alter the appearance of the eye. This has been done by placing 10Δ of base-down prism in the right lens. To help prevent a thick lower edge on the right lens, a frame should be chosen with a narrow vertical dimension. To help camouflage lens thickness, the lenses have been given an antireflection coating. (Courtesy Laurie Pierce, Tampa, FL.)

Figure 21.18 As in the previous figure, the apparent location of the right artificial eye and orbit is moved upward using 12Δ of base-down prism. To help in balancing the horizontal levels of the two eyes, the maximum recommended amount of 4Δ of base-up vertical prism is used over the seeing left eye. This moves the apparent location of the left eye downward. (Courtesy Laurie Pierce, Tampa, FL.)

Example 21.10

Suppose a right prosthetic eye is physically displaced downward as in Figure 21.17, *A*. How could the eye be made to look more normal?

Solution

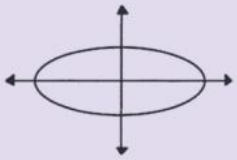
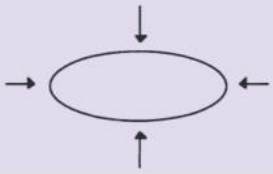
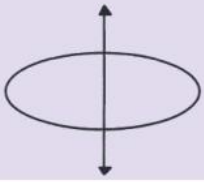
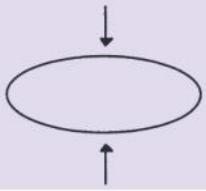
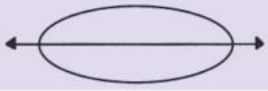
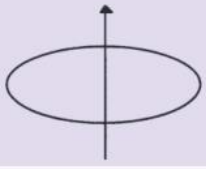
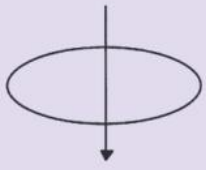
Increasingly larger amounts of base-down prism are held in front of the prosthetic eye until, with 10Δ of base-down prism, the eye appears more evenly placed relative to the seeing eye. To prevent having the right lens appear thick at the bottom, use a frame with a small vertical size (small B dimension). To make the prism less obvious, an antireflection coating should be used.

It is possible to split the prism unevenly between the left and right eyes. If the prism is split, the maximum amount of vertical prism should not exceed 4Δ in front of the seeing eye. Exceeding 4Δ may cause postural changes and errors in the perceived location of objects. In this case, one might use 7Δ base down before the right eye and 3Δ base up before the left eye.

A second example is shown in Figure 21.18. Here, the prism is split because it requires an even greater amount of prism to bring the two eyes closer to the same horizontal plane. Twelve prism diopters base down are used in front of the right nonseeing eye, and 4Δ of base-up prism are used in front of the left seeing eye.

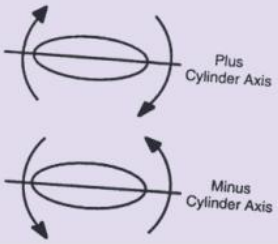
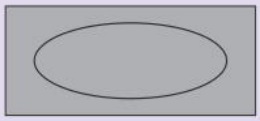
Table 21.1 summarizes the use of lenses for cosmetic effects.

TABLE 21.1 Using Lenses to Achieve a Desired Cosmetic Effect

Problem	Desired Cosmetic Effect	Lens Solution
Eye looks small	Make the eye look bigger 	Use a plus sphere lens
Eye looks large	Make the eye look smaller 	Use a minus sphere lens
Eye not open as wide as the seeing eye. (Fissure looks too small vertically.)	Widen the fissure vertically 	Use a plus cylinder axis 180
Eye open wider than the seeing eye. (Fissure looks too large vertically.)	Close the eye somewhat 	Use a minus cylinder axis 180
Eye looks too small horizontally	Widen the horizontal appearance of the eye 	Use a plus cylinder axis 90
Eye looks too wide horizontally	Narrow the horizontal appearance of the eye	Use a minus cylinder axis 90
Eye looks too low	Raise the apparent height of the eye 	Use base-down prism
Eye looks too high	Lower the apparent height of the eye 	Use base-up prism

Continued

TABLE 21.1 Using Lenses to Achieve a Desired Cosmetic Effect—cont'd

Problem	Desired Cosmetic Effect	Lens Solution
Eyelid is slanted	Cause the rotated appearance of the lid to change in tilt and match the horizontal look of the seeing eye 	Rotate the plus cylinder axis against the direction of desired tilt, or rotate the minus cylinder axis with the direction of desired tilt
Eyelid has unsightly appearance or scarring of the lids or orbital area	Reduce visibility of the eye 	Use tinted lenses—solid tint for overall masking or gradient tint to mask the upper areas. If tints are not used, avoid antireflection coatings

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PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. A form of aniseikonia occurs in a limited but useful amount in those whose eyes are identical to one another—both eyes may not have refractive error, or both may have identical refractive error. This form of aniseikonia is used to help in determining the location of an object in space and is called
   a. symmetrical aniseikonia
   b. anatomic aniseikonia
   c. optical aniseikonia
   d. axial aniseikonia
   e. physiologic aniseikonia

2. A right lens has a power of +3.00 D and is made from CR-39 plastic with an index of 1.498. It is 4.3 mm thick and has a front surface refractive power of +8.50 D. The lens is to be worn at a vertex distance of 13 mm. What is the spectacle magnification for this lens?
   a. 4.49%
   b. 6.58%
   c. 7.67%
   d. 8.32%

3. True or false? The amount of magnification produced by an ametropic eye compared with the image size produced by a "standard emmetropic eye" is called *relative spectacle magnification.*
   a. True
   b. False
4. Spectacle magnification has two parts: a shape factor and a power factor. Which of the following is ***not*** a part of the shape factor?
   a. lens thickness
   b. index of refraction
   c. distance from the lens back surface to the entrance pupil of the eye
   d. the front surface curvature of the lens in diopters
5. If an eye has axial ametropia and is too long or too short, the image size will be larger or smaller than it would normally be. According to Knapp's law, using spectacle lenses on such an eye will bring the retinal image size back to normal. Which of these statements about Knapp's law is correct?
   a. Knapp's law is not just theory. It can be depended upon clinically.
   b. Knapp's law does not always hold true in clinical practice.
6. True or false? Aniseikonia symptoms are often the same as those experienced with either uncorrected refractive error or oculomotor imbalances. The difference is that with aniseikonia, symptoms either are not helped by the correction or appear after refractive and oculomotor problems are corrected.
   a. True
   b. False
7. Which of the following lens and frame options will ***not*** help to reduce the possibility of aniseikonia becoming a problem?
   a. Use a frame with a short vertex distance.
   b. Use a frame with a small eye size.
   c. Use lenses with steepened base curves.
   d. Use an aspheric lens design.
   e. Use a high-index lens material.
8. A wearer has anisometropia, and both right and left lenses are plus in power. One lens is higher plus than the other. To reduce aniseikonia, all of the following responses are appropriate **EXCEPT ONE**. Which possibility is ***not*** appropriate?
   a. Thin the higher plus lens.
   b. Steepen the base curve of the higher plus lens.
   c. Choose a frame with a minimum vertex distance.
   d. Increase the center thickness for the lower plus lens.
9. One lens is plus and the other minus. We want to minimize aniseikonia. All of the following are ***wrong*** things to do **EXCEPT ONE**. Which one is the ***correct*** thing to do?
   a. Steepen the base curve of the plus lens.
   b. Increase the vertex distance for the minus lens by moving the bevel to the back part of the lens edge.
   c. Thin both lenses.
   d. Choose a frame with a smaller vertex distance.
   e. Use a frame with a larger eye size.
10. One possibility for determining the percent magnification difference between right and left lenses is to estimate what this difference might be based on the spectacle lens prescription. This is done using a rule of thumb that multiplies a certain percent by the difference between the spectacle lens prescriptions for left and right eyes. At the time of this writing, the preferred closest rule of thumb estimates
    a. 0.5% magnification difference for each diopter of anisometropia.
    b. 1.0% magnification difference for each diopter of anisometropia.
    c. 2.5% magnification difference for each diopter of anisometropia.
    d. 3.5% magnification difference for each diopter of anisometropia.
11. Here are some statements about the value of modifying spectacle lenses to lessen aniseikonia. Which of these statements is most accurate?
    a. Compensating for aniseikonia by modifying the spectacle lenses is of no value.
    b. Compensating for aniseikonia by modifying the spectacle lenses is only of minimal value since it is seldom done in practice.
    c. Compensating for aniseikonia by modifying the spectacle lenses has about a 50-50 chance of making a subjectively noticeable difference from the wearer's perspective when compared with no compensation for aniseikonia.
    d. Compensating for aniseikonia by modifying the spectacle lenses makes a subjectively noticeable difference for a significant majority of wearers when compared with no compensation for aniseikonia.
12. What is a bitoric spectacle lens?
    a. A bitoric spectacle lens is one that has two lens curves on one surface of the lens.
    b. A bitoric spectacle lens is one with aspheric surfaces on both the front and back of the lens.
    c. A bitoric spectacle lens is one with two curves on the front and two curves on the back of the lens.
    d. A bitoric spectacle lens is one with an aspheric front surface and an atoric back surface.
13. Vertical imbalance situations are most troublesome to the wearer when they are
    a. long standing.
    b. of recent origin.
14. Contact lenses are used to overcome vertical imbalance because
    a. spectacle lenses create vertical imbalance at near, but contact lenses do not.
    b. contact lenses have vertical imbalance, but that imbalance is smaller and therefore not troublesome.
    c. contact lenses can be made with prism ballasting on one lens to correct for vertical imbalance.
    d. contact lenses are not used to overcome vertical imbalance problems.
15. How does the option of using two difference pair of single-vision lenses, one for distance and one for near, address the problem of vertical imbalance? Choose the correct response for how the option overcomes (or does not overcome) the problem of vertical imbalance.
    a. This option provides an equal but opposite amount of prism to counteract the imbalance.
    b. The imbalance is still present for off-axis viewing, but this option allows the wearer to look through areas of the lenses where imbalance is not problematic.
    c. This option presents a compromise situation where vertical imbalance is reduced at near but increased in distance viewing.
    d. This option is of no help in correcting or avoiding imbalance and should not be used.
16. True or false? The best correction for vertical imbalance at near caused by the spectacle lens correction of anisometropia is always the full calculated amount of prismatic effect induced at the reading level.
    a. True
    b. False
17. Traditional slab-off prism is ground on the
    a. most plus or least minus lens.
    b. stronger of the two lenses.
    c. most minus or least plus lens.
    d. thicker lens.
    e. dominant eye.

18. True or false? It is not possible to have an optical laboratory calculate the amount of slab-off prism required for vertical imbalance. That calculation must be done by the eye care practitioner.
- **a.** True
- **b.** False

19. A prescription reads as follows:
O.D. −3.50 −1.00 × 090
O.S. −5.50−1.50 × 090
Add: +2.00 D
Using the traditional method for calculating vertical imbalance, how much vertical imbalance is present for a reading level 10 mm below the distance OCs?
- **a.** 1.10Δ base down O.D.
- **b.** 2.00Δ base down O.S.
- **c.** 2.00Δ base down O.D.
- **d.** 2.50Δ base down O.S. and 0.50Δ base up O.D.
- **e.** none of the above

20. A prescription reads as follows:
O.D. +5.00 −2.00 × 180
O.S. +3.00 −2.00 × 090
Would there be vertical imbalance manifested at a reading level 10 mm below the OCs?
- **a.** Yes
- **b.** No

21. Using traditional methods for calculating vertical imbalance, *how much* slab-off prism would have to be ground on *which lens* to correct vertical imbalance completely at a point 10 mm below the distance OC for the following prescription?
O.D. +2.75 D sphere
O.S. −2.75 D sphere
- **a.** 2.75Δ base down O.D.
- **b.** 0.00
- **c.** 5.50Δ base up O.D.
- **d.** 5.50Δ base up O.S.
- **e.** none of the above

22. What amount of vertical imbalance at the reading level is created by the following lens correction? The reading level is 8 mm below the distance OC. Note that the lens powers are written in plus-cylinder format.
O.D. + 3.00 + l.00 × 180
O.S. + 1.00 + 0.75 × 180
- **a.** 1.60Δ
- **b.** 4.60Δ
- **c.** 1.80Δ
- **d.** Not enough information is given.
- **e.** Enough information is given, but none of the above answers are correct.

23. A prescription reads as follows:

$$R: -5.50 - 2.50 \times 030$$
$$L: -2.50 - 1.50 \times 160$$
$$\text{Add}: +2.00\,\text{D}$$
$$\text{Frame B dimension} = 48\,\text{mm}$$
$$\text{Seg height} = 20\,\text{mm}$$

If the assumption is that the reading level is 5 mm below the seg line, what amount of vertical imbalance is present in the lens pair? (Use the cosine-squared method for calculating the imbalance, and give the answer to the nearest quarter diopter.)
- **a.** 3.25Δ
- **b.** 3.50Δ
- **c.** 4.00Δ
- **d.** 4.50Δ

24. A progressive addition lens has a fitting cross height 4 mm above the PRP. It is said to have a minimum fitting height of 14 mm. If we were to want to fully correct for vertical imbalance at the reading level, what distance would be used to do our calculation?
- **a.** 4 mm
- **b.** 10 mm
- **c.** 12 mm
- **d.** 14 mm
- **e.** 18 mm

25. What is an argument against placing the slab line low (at the top of the circle around the NRP)?
- **a.** The wearer is being overcorrected for vertical imbalance for the intermediate viewing area.
- **b.** The line will be distracting for distance viewing.
- **c.** The line will be distracting for intermediate viewing.
- **d.** Many people drop their eyes down to the point on the lens where the add reaches 85% and use that area for casual near viewing.

26. The dispenser chooses to place the slab line at the level where the imbalance reaches 1Δ of prism. The power in the 90-degree meridian of the right lens is −6.00 D. The power in the 90-degree meridian of in the left lens is −3.50 D. How far below the level of the PRP would the slab line be placed?
- **a.** 1 mm
- **b.** 2 mm
- **c.** 3 mm
- **d.** 4 mm

27. True or false? For a progressive addition lens, one should always use the full amount of vertical imbalance correction as calculated from the PRP to the NRP.
- **a.** True
- **b.** False

28. True or false? Two spectacle lenses have the same power, but their base curves and center thicknesses are different. For a point 10 mm below their distance centers, these two lenses may not have the same prismatic effect.
    a. True
    b. False
29. True or false? Reducing the amount of aniseikonia may also reduce the amount of vertical imbalance correction needed for a prescription with anisometropia.
    a. True
    b. False
30. For a high plus anisometropic correction, how will vertical imbalance calculated using Remole's method compare with the amount of vertical imbalance calculated using Prentice's rule?
    a. The calculation using Prentice's rule will yield the higher amount of imbalance.
    b. The calculation using Remole's method will yield the higher amount of imbalance.
    c. Both methods will yield the same amount of imbalance.
31. A blind, prosthetic left eye is physically lower than the right seeing eye. Otherwise, the two eyes match perfectly. What could be done to give a better overall appearance?
    a. Use a plus lens in front of the left eye.
    b. Use a minus lens in front of the left eye.
    c. Use base-up prism in front of the left eye.
    d. Use base-down prism in front of the left eye.
32. A right, prosthetic eye has a palpebral aperture that is vertically larger than the left seeing eye. However, the horizontal dimension of the aperture of the prosthetic eye is definitely not larger than the seeing eye. What would be your first trial lens option for the prosthetic eye?
    a. A plano plus cylinder lens axis 180
    b. A plano plus cylinder lens axis 090
    c. A plano minus cylinder lens axis 180
    d. A plano minus cylinder lens axis 090
    e. A plus sphere lens

22

Absorptive Lenses

CLASSIFICATION

Absorptive lenses are classified by *two variables*. The first is *the tint of the lens* itself, and the second is *the lens transmission*. Tints of the same basic color are labeled by a variety of names, depending on the manufacturer or, in the case of plastic lenses, the name of the dye used to tint the lens. Differences of shade are sometimes discernible when two manufacturer's products are held side by side. For this reason, a record of the lens source should be entered on the wearer's record so that replacement lenses will match the original tint. (That having been said, it should be remembered that plastic lens tints will fade over time. Replacing only one lens without sending the lenses to the lab may result in a mismatch.)

The relative absorption of a lens is most often denoted as either percent transmission or percent absorption. (Twenty percent transmission is the same as 80% absorption.)

Absorption used to be denoted by a letter (such as A, B, C, or D) or by a number (such as 1, 2, or 3). The higher the number or the further down the alphabet, the darker the tint would be.

Because this system was developed for tinted glass lenses that change transmission with increasing thickness, specific transmission will vary for different powered lenses having the same number or letter designation. Because this system may still have limited usage, the dispenser must be aware of these potential differences.

Problems of Uniform Transmission Inherent in Pretinted Glass Lenses

It should be noted that the specified transmission for a pretinted glass lens applies to a 2-mm thick plano lens. Any departure from this thickness will result in changes in the expected transmission. The individual who was previously wearing a C tint in a + 2.00 D glass lens may therefore find the same tint irritatingly dark when the prescription is changed to +3.50 D.

Glass lenses that vary in thickness from one area of the lens to another will also show proportional changes in transmission. The high minus lens will have a lighter central portion, darkening rapidly toward the periphery (Figure 22.1, *A*); the plus lens shows a darkened central zone with the tint lightening to the normally expected shade at the periphery (see Figure 22.1, *B*). Perhaps the most unusual is a high, near plano minus cylinder lens. In this case, a lighter band runs across the lens corresponding to the location of the minus cylinder axis (see Figure 22.1, *C*). Fortunately, few absorptive lenses require glass lens material, making the problem an infrequent occurrence.

THE EFFECT OF VISIBLE AND NONVISIBLE LIGHT ON THE EYE

Light is electromagnetic radiation found in the wavelength range that includes ultraviolet (UV), visible, and infrared (IR) radiation. Not all of these wavelengths cause an activation of photoreceptors that produce vision (Figure 22.2). Light is interpreted as color according to the length of the light wave that strikes the retina.

The visible spectrum is considered to be between 380 and 760 nm.[1] However, light with a wavelength as short as 309 nm may be seen if it is of sufficient intensity. Light having sufficient intensity and a wavelength as short as 298 nm could be seen if it were not absorbed by the crystalline lens before reaching the retina.[2]

Much of the "light" in the UV and IR regions of the spectrum that strikes the eye never reaches the retina. Instead it is absorbed by the cornea, aqueous humor, crystalline lens, or vitreous humor of the eye. If too much of this "light" is absorbed by the individual eye structure in sufficient quantity or over an excessively lengthy period, it can be potentially harmful.

The Effects of Ultraviolet Radiation

"Light," or more properly, electromagnetic radiation with a wavelength shorter than 400 nm, is known as *UV radiation*. UV radiation can be further subdivided into four regions.[3]

1. UVA 315–380 nm
2. UVB 290–315 nm
3. UVC 200–290 nm
4. UV vacuum 100–200 nm

UVA radiation has the longest wavelength band and, relatively speaking, is the least harmful of the three radiation bands. It causes the skin to tan. UVB radiation has shorter wavelengths and a higher energy than UVA radiation. If present in sufficient quantity, long enough duration, or both, UVB radiation causes sunburn, photokeratitis, cataracts, and retinal lesions. UVC radiation is still higher in energy but is effectively filtered out by the earth's ozone layer. UV vacuum radiation is present outside the earth's atmosphere but is filtered by the atmosphere. The shorter the wavelength, the more biologically harmful the radiation will be.

There are a number of negative effects attributed to excessive exposure to UV radiation. The question becomes what constitutes "excessive exposure?" The answer is not simple. Single, high-level amounts of UV radiation can be damaging, but so can long-term, low-level amounts of UV radiation exposure.

UV radiation is a normal component of sunlight. Fortunately, the ozone layer normally filters out a large portion of shorter wavelength UV radiation.

UV radiation from sunlight is more intense between the hours of 10 AM and 2 PM, with 60% of total UV radiation taking place during these hours.[1] The total annual amount of UV radiation is greater in geographic regions closer to the equator, and the amount of UV radiation increases in intensity at high altitudes.

Sand and snow increase the amount of UV radiation an individual receives because sand reflects 20% to 30% of UV light. Fresh snow reflects 85% to 95% of the light that strikes it as compared with only 3% for grass.[4] This makes UV protection for skiers absolutely essential.

Other sources of UV radiation include UV-type lamps and welding.

Ocular Damage Caused by Ultraviolet Radiation

An example of ocular damage caused by a single dose of high-level UV radiation is a *welder's burn*. In a welder's burn, the cornea and conjunctiva absorb UV light between 210 and 320 nm.[1] The excessive exposure to these UV wavelengths results in inflammation of the cornea and conjunctiva known as *photokeratitis*. The same photokeratitis may result from exposure during snow-related activities and is referred to as *snow blindness*. It takes approximately 6 h after a burn has occurred before the onset of pain. Fortunately, although the symptoms of grittiness, intense light sensitivity, excessive tearing, redness, and difficulty in opening the eyes are severe, in most cases the cornea heals and symptoms are gone in 6 to 24 h.

An example of ocular damage caused by long-term, cumulative, low doses of UV radiation is the *formation of cataracts*. People who live where UV radiation is high (at high altitudes or in desert or tropical areas) develop cataracts earlier in life. As an example, those who live in an area where the average amount of sunlight exposure is 12 h have four times the amount of cataract formation compared with those who live in areas with a daily average of 7 h.[5]

Welder's burn and cataracts are not the only eye-related problems induced by UV radiation. Another serious problem is retinal damage, particularly for the *aphake* (person without a crystalline lens) since the lens no longer absorbs light between 300 and 390 nm but allows it to fall on the retina. Today, cataract surgery is followed by the implantation of an intraocular lens to replace the cataract-clouded crystalline lens. Individuals who have an intraocular lens implant are called *pseudophakes*. Although presently used intraocular lens implants are UV absorbing, UV protection in spectacle lenses is still advisable.

A *pterygium* is a growth of tissue that begins on the white of the eye and extends onto the cornea. With continued growth, it can travel to the center of the cornea, blocking clear vision. There is a correlation between the incidence of pterygia and UV exposure. A similar condition known as a *pinguecula* may also be UV related. A pinguecula manifests itself as a yellowish thickening of the conjunctiva, usually on the nasal side of the cornea.

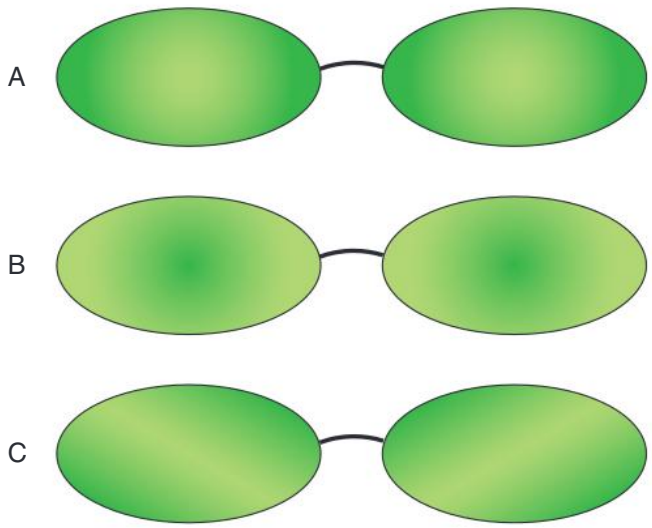


Figure 22.1 Glass lenses with the tint in the lens material itself will vary in transmission as the thickness of the lens varies. **A,** A high minus prescription will be lightest in the middle and will darken toward the edges. **B,** A high plus prescription will be darkest in the middle and will lighten toward the edges. **C,** A plano, high minus cylinder will be lightest along the cylinder axis. Here the minus cylinder axis for the wearer's right eye is about 140 and for the left eye, about 050. This only occurs with high cylinders when the tint is within the glass itself.

Drugs That Heighten Ultraviolet Damage

Certain drugs increase the amount of damage that can be done by UV radiation. These include, but are not limited to, sulfonamides, tetracyclines, certain diuretics, tranquilizers, and oral contraceptives. This means that in addition to those effects of UV radiation that have already been discussed, individuals taking these drugs are more prone to sunburn and skin cancer. Individuals known to be taking these medications should be advised to use UV protective eyewear and use sunscreen for skin protection when appropriate.

Who Should Have Ultraviolet Protection?

UV damage to the eye is known to be cumulative. Because UV radiation affects everyone over time, the best way to reduce UV-related eye disease is to wear UV-absorbing spectacles and sunglasses early in life. Factors regarding protection from UV light are summarized in Box 22.1.

Eyewear That Blocks Ultraviolet Radiation

There are a number of lens options available to protect against UV radiation. Some require special ordering, but many lenses come with UV filtering as a basic part of the lens.

1. *Lenses with the UV filter directly added to the lens material*
2. *Lenses with the UV filter in the coating*—Many lenses come with a coating intended to protect the lens material. Since UV radiation can damage some materials over time, a UV blocker is often part of that coating. These include all polycarbonates and many high-index plastic lenses.
3. *Lenses with a dyed-in UV filter*—Plastic lenses can be made UV inhibiting by immersion in a hot UV dye in the same manner as is used to tint a lens.
4. *Polarizing lenses*—Good-quality polarizing lenses are made to block UV radiation, although the polarization process has nothing to do with blocking UV light.

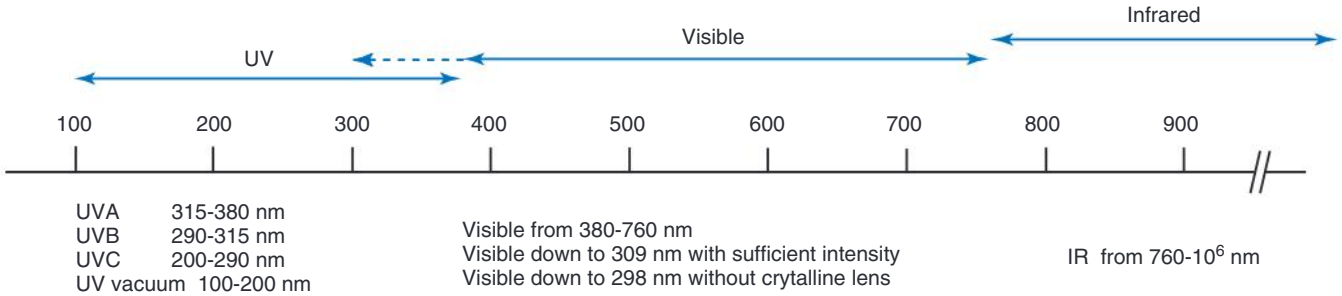


Figure 22.2 The light spectrum: ultraviolet (*UV*), visible, and infrared (*IR*).

BOX 22.1 Individuals With a Greater Need for Ultraviolet (UV) Protection

Those with the Following Conditions:
- Beginning cataracts
- Macular degeneration
- Pterygia
- Pinguecula
- Aphakia
- Pseudophakia

Those Who are Taking Medications, Including:
- Sulfonamides
- Tetracyclines
- Diuretics
- Tranquilizers
- Drugs for hypoglycemia
- Oral contraceptives

(*This list is only a sampling of drugs that may increase UV damage. It is by no means all-inclusive.*)

Those in the Sun Under the Following Conditions:
- Outdoors between 10 AM and 2 PM in summer
- Outdoors long hours (especially children at play)
- Snow skiing
- Sun bathing
- In high-altitude conditions
- Near the equator

Persons Who are Around UV Sources, Including:
- Welders
- Those working near UV lamps, such as dentists and dental technicians
- Those in industries that use UV radiation

5. *Photochromic lenses have UV-blocking properties.* In their darkened state, photochromic lenses are considered sufficiently protective against UV light.
6. *Lenses that go beyond UV protection*—There are lenses designed to go beyond simple UV protection. Some may also block out a certain percentage of short wavelength (primarily blue) visible light. Others are made to block specific ranges of shorter wavelength light rays. These are often referred to as *glare control lenses* and are described later in this chapter.

It is worth noting that there is not agreement on the importance of blocking UV all the way up to 400 nm. Thus, a lens that completely blocks UV radiation up through 380 nm is considered sufficient according to many standards. There are other standards that do not consider UV absorption complete until radiation up through 400 nm is absorbed.

Checking for Ultraviolet Absorption

Lens transmissions may be checked using a photometer (Figure 22.3). Though photometers are helpful, at the time of this writing, they should not be totally relied upon for absolute UV measurements. As Torgersen[3] points out, photometers typically:
- are not able to accurately determine absolute UV transmittance.
- disproportionately weight the waveband of 360–400 nm.
- do not cut off at the UVA limit of 380 nm, but measure on up through 400 nm.
- are affected by the power of the lens.

It is therefore advisable for the practitioner to be very familiar with the absorptive properties of individual lens materials.

It should be remembered that the dyes used to make a regular plastic lens into a UV-blocking lens are only good for a finite number of applications before they must be replaced. Even when ordered, it is feasible that UV protection may be inadvertently overlooked in the laboratory. Photometers are helpful to determine if dyes have been applied.

Selecting a Frame

Here is what to look for when selecting a frame for sunglasses or for serious protection against UV radiation. The frame should have a large lens area. It should be fit close to the face with minimum vertex distance. Wraparound frame styles are best. Note: When wraparound styles are used for prescription eyewear, the prescription may need to be compensated for lens tilt (see Chapter 18). To get maximal protection, a cap or hat with a large visor or brim will help considerably. (For a summary of UV protection options, see Box 22.2.)

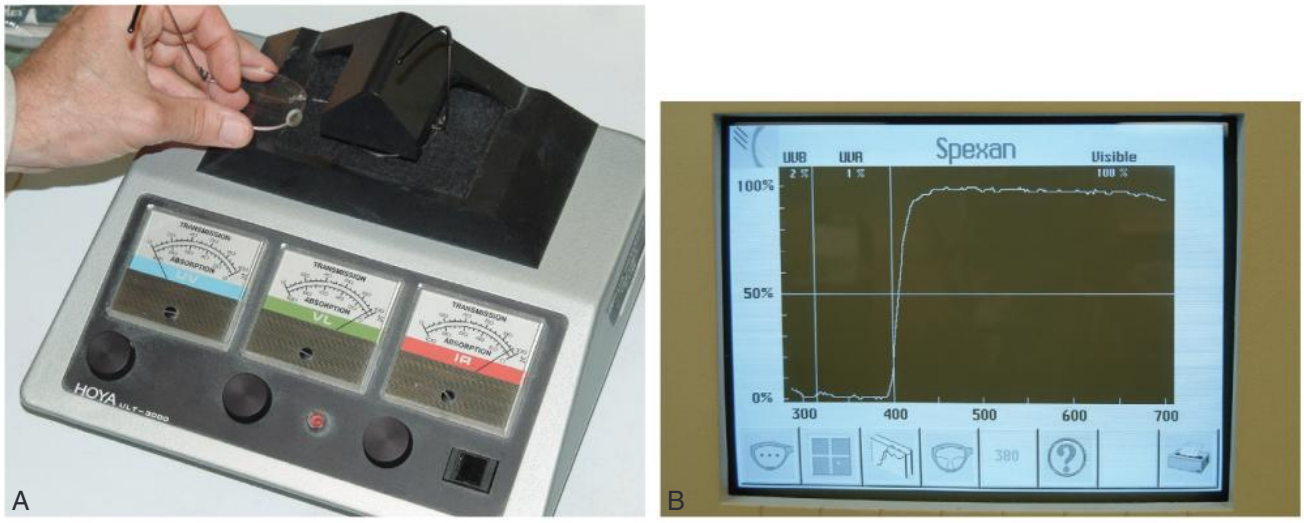


Figure 22.3 Lenses ordered with ultraviolet (UV) absorption should be checked using a UV meter. These light transmission meters measure UV, visible (VL), and infrared (IR) light. The lens being measured is blocking virtually all UV light and is transmitting most of the visible and IR radiation. **A,** A freestanding light meter. **B,** The screen of a lensmeter equipped with built-in transmission measuring capabilities.

BOX 22.2 Options for Protecting the Eyes From Solar Ultraviolet (UV) Radiation

Headgear Wear
- Sun visor
- Cap
- Wide-brimmed hat

Prescription Lenses
- Lenses specifically made to be UV blocking
- Polycarbonate lenses
- High-index lenses with a UV-absorbing coating
- UV-dyed plastic lenses
- Photochromic lenses
- Glare control–type lenses
- Quality polarizing lenses

Eyeglass Frames That Have the Following:
- A short vertex distance
- Face form

Sunglasses Wear
- UV-absorbing sunglasses
- Lenses that cover a large area
- Wraparound sunglasses

Ultraviolet Index

The UV index is a measure of UV radiation. The U.S. Weather Service and the Environmental Protection Agency, along with the World Health Organization, use a UV index on a scale of 1 to 11+ with intensities from low to very high. The index is categorized as follows:

UV Index	Exposure Level
0–2	Low
3–5	Moderate
6–7	High
8–10	Very high
11+	Extreme

Any UV index reading will vary from day to day, time of day, and from place to place. The intent of a UV index is to make the general public aware of UV radiation levels and encourage eye and skin protection.

The Effects of Short Wavelength Visible Light (Blue Light)

As was seen with ultraviolet light, the shorter the wavelength the higher the energy. Shorter wavelength UVC and UVB light is more damaging to the eyes than longer wavelength UVA. The energy levels for the visible spectrum follow the same pattern. Shorter wavelength blue light has higher energy than longer wavelength red light. It is possible to damage the retinal cells using intense blue light. Yet studies showing that this threshold is being reached under normal viewing circumstances are not definitive.

The question then becomes, in what situations might shorter wavelength blue light become harmful?

There have been numerous lenses and coatings marketed with the implied or stated purpose of protecting the eyes from the blue light emitted from electronic screens and monitors. Yet it is difficult to make the case for blue light from digital devices being harmful to the eyes. As Dr. Karl Citek states, "The amount of blue light experienced from the sun outdoors greatly exceeds what any typical device can emit."[6] Indeed, shorter wavelength blue light of sufficiently high intensity can be harmful to the eyes, but care should be taken not to use a blanket label for shorter wavelength blue light as being "harmful blue light" if the circumstances under which blue light may be harmful do not correspond to the circumstances for which the use of the blue-light–blocking lens is being advocated.

Blue-light–blocking lenses or lens coatings have also been assumed to decrease digital eye strain. Even this is difficult to objectively verify. Studies do not all agree. One well-respected study comparing blue light filtering lenses to an equiluminant neutral density filter concluded that the blue-light–blocking lenses were no more effective at reducing symptoms of digital eye strain than neutral density filter lenses.[7]

At this point in time, the advantage of blue-light–blocking lenses that has the most agreement centers around how they can help in the regulation of sleep cycles. The hormone *melatonin* is generated by the pineal gland[8] and aides in the sleep cycle. Its production in the body helps with timing of circadian rhythm. Our circadian rhythm has to do with both our 24-h internal clock and in how easily we are able to get to sleep. Melatonin production is suppressed by light—particularly blue light with a peak sensitivity between 446 and 477 nm.[8] Lenses that block blue light in and around these wavelengths are able to impede the capacity of bright light to suppress melatonin production.[8] Thus, wearing these kinds of blue-light–blocking lenses in the evening may be helpful in preventing sleep cycle disruption.

It should be noted that, for this study, orange lenses that blocked almost all light of wavelengths below 550 nm were used. (Light with wavelengths above 550 nm appears to have little effect on melatonin suppression.) For this study, blue light was almost totally blocked. It is unclear what percent of blue light needs to be blocked to prevent melatonin suppression. Blue-light–attenuating lenses that are intended for full-time wear are practically clear. (Lenses that nearly block all blue light appear yellow or orange.) These clear lenses concentrate primarily on blocking light between 400 and 450 nm. Longer wavelength blue light is blocked by a lesser amount.

The Effects of Infrared Radiation

At the present time, there is little conclusive evidence in the literature that would indicate any undesirable effects resulting from the IR component in sunlight in ordinary viewing.

Previously it was thought that the solar retinitis caused by the intense exposure of looking directly at the sun for a long period of time was a result of the heat-producing IR component alone. Scientists at the Medical College of Virginia, however, found the eye to be 800 times more susceptible to damage from the blue end of the spectrum than from the near IR. It appears that solar retinitis is due to a combination of photochemical damage from short wavelength (UV and blue) radiation and thermal damage from long wavelength IR.[1]

IR radiation, when combined with UV radiation and blue light, can adversely affect the crystalline lens. Over a prolonged period of time, this will cause opacification. This lens opacification is commonly referred to as "glass blower's" or "furnace men's" cataract.

Common sources of IR are direct sunlight, molten substances such as glass and metal, arc lamps, and IR lamps.

In looking at the transmission curve of a given lens, remember that simply because there is a drop in the transmission of IR in the region nearest the visible spectrum, there may not be this same absorption in the longer wavelength IR region. Many lenses that absorb strongly in the near IR transmit a great deal in the longer wavelengths. Therefore, if a lens is to be chosen for IR absorption characteristics, a transmission curve showing the full range of the IR spectrum is needed.

REQUIRED AMOUNTS OF ABSORPTION

Practitioners are continually asked how dark a tinted lens should be for best protection or how light a fashion tint must be to not adversely

affect the wearer's vision. The answer is considerably more complex than might be expected since much depends on the activities for which the lens is to be used.

If the only object is the comfort of the wearer, then the decision is often subjective and is fairly accurately determined through the wearer's past experience. Other factors, however, must be considered as well. As far as actual improvement of vision, Miller[9] found that for high levels of illumination, sufficiently dark sunglasses will improve visual discrimination for certain types of targets but not for others. In other words, for high illumination, a person's ability to see clearly may be helped by dark lenses, and his or her visual comfort most certainly will improve.

How Much Tint Is Enough?

Normal transmission for sun lenses is between 8% and 40% according to ANSI Z80.3–2018 standards. Yet a sun lens that transmits more than 30% may not help the average wearer enough in full sunlight.[10] Unless the back surface of the sunglass lens is antireflection (AR) coated, sun lenses that transmit less than 15% can present problems because of reflected glare from the back surface.

According to ANSI Z80.3–2018 sunglass standards, general purpose sun lenses used for driving should not be darker than 8%. For sunglass lenses used for special purposes such as skiing, mountain climbing, or use on the beach, transmission may go as low as 3%, although they are not appropriate for driving.[11]

At the lower end of the transmission spectrum, it was found that acuity increased with a 10% neutral density filter. But for persons more than 40 years of age, vision worsened if the filter was any darker than 10%.[12]

It should be noted that people who are exposed to sunlight for long periods of time on a continual basis will require sun lenses that transmit 15% or less. Hecht et al.[10] found that a single exposure to ordinary bright sunlight for 2 or 3 h caused dark adaptation to start 10 or more minutes later than usual and then slowed the process itself so that normal night vision was not reached until several hours later than usual.

For example, if a person (such as a lifeguard) is exposed to bright sunlight every day for long periods of time, his or her dark adaptation does not return to what it used to be even after a full night's darkness. If this continues for 10 days of unprotected high exposure to sunlight, it will impair dark adaptation to such an extent that 3 or more days of nonexposure are required for dark adaptation to return to its previous level. This loss of dark adaptation can be prevented by wearing sunglasses that allow only a transmission of between 10% and 15% of sunlight. For the person exposed to bright sunlight, even if that person is wearing commercially available tinted lenses that transmit 35% to 50% of the light, this will not be dark enough to prevent impairment of dark adaptation.[12] In fact, "it is strongly recommended that sunglasses transmitting 10% or less of visible light be used by all persons who, while working in bright sunlight during the day, will be expected to perform critical night duties soon afterward.[10]" In short, anyone who has a job that requires seeing well at night should wear sunglasses if they are exposed to bright sunlight for two or more hours a day.

The Hazards of Too Much Tint

As just discussed, there are certain situations where a large amount of *absorption* is quite desirable. In contrast, there are also circumstances in which a maximum of light *transmission* is desirable. When considering darker fashion tints, wearers should be warned of the reduction in visual acuity in dimly lit conditions.

Tinted Lenses and Night Driving

A commonly occurring situation that demonstrates the hazards of too much tint for existing conditions is night driving. At night with eyes adapted to a light intensity of 0.1 mL through a clear glass windshield, the visual acuity of an individual who normally sees 20/20 will be reduced to 20/32. This is not due to the windshield itself but it is simply a result of reduced illumination. Any tinted material between the observer's eye and the object being viewed will further reduce acuity.[13]

It should be obvious that a lens tinted only slightly more than the lightest available shade quickly becomes a potential hazard under circumstances such as night driving, which may otherwise be considered normal.

Another factor in the determination of the amount of tint is age. As age increases, performance differences observed while wearing certain optical filters decreases. In other words, a person's ability to work effectively under a situation of reduced illumination decreases as he or she ages.

In spite of evidence to the contrary, some wearers insist that a light tint at night is helpful in reducing the glare of oncoming headlights. This is likely due to the ability of a tint to reduce some internal lens reflections and some resulting headlight flare. An AR coating is better at reducing internal lens reflections. Rather than using tinted lenses, an AR coating will reduce oncoming headlight annoyance and will increase the wearer's contrast sensitivity by increasing available light.

COLOR CHARACTERISTICS

There are many different lens colors, shades, and hues of lenses available. This section begins by presenting characteristics of the more common lens colors.

Clear Crown Glass and CR-39 Plastic

Crown glass and CR-39 plastic both transmit approximately 92% of visible light. The 8% not transmitted is lost through reflection. All UV light less than 290 nm is absorbed by crown glass (Figs. 22.4 and 22.5). Unfortunately, from a practical standpoint, it is the UV light from 290 on up to the visible light that can be more disturbing.[9] Most UV light less than 290 nm in the UVC and UV vacuum light ranges, although the most damaging to the eye, will have already been absorbed by the atmosphere.

Crown glass transmits infrared (IR) in the same proportion as it does visible rays.

CR-39 plastic used in normal spectacle lens wear contains a UV light inhibitor that does not block all UV light but does block UV light less than 350 nm.

Pink

Pink has been widely used in the past and is still used to a limited extent. Pink is also referred to as rose. Pink tints have a uniform transmission across the visible spectrum (see Figure 22.5) and therefore do not cause any color distortion for the wearer.

Pink tints had been used for unfavorable indoor lighting situations such as bright fluorescent lighting or glare in the work area. The best solution to those problems is a change in lighting rather than an indoor tint. Light tints do reduce some internal lens reflections but not nearly as effectively as an AR coating. Internal lens reflection problems are better helped with an AR coating.

It is not advisable to use an indoor tint much darker than 80% transmission for full-time wear. This is especially true at night or under very dim illumination because contrast sensitivity and reaction times are reduced when worn.

Yellow

Yellow-tinted lenses (Figure 22.6) are especially subject to myth and speculation. Can people see better with yellow lenses? After reviewing

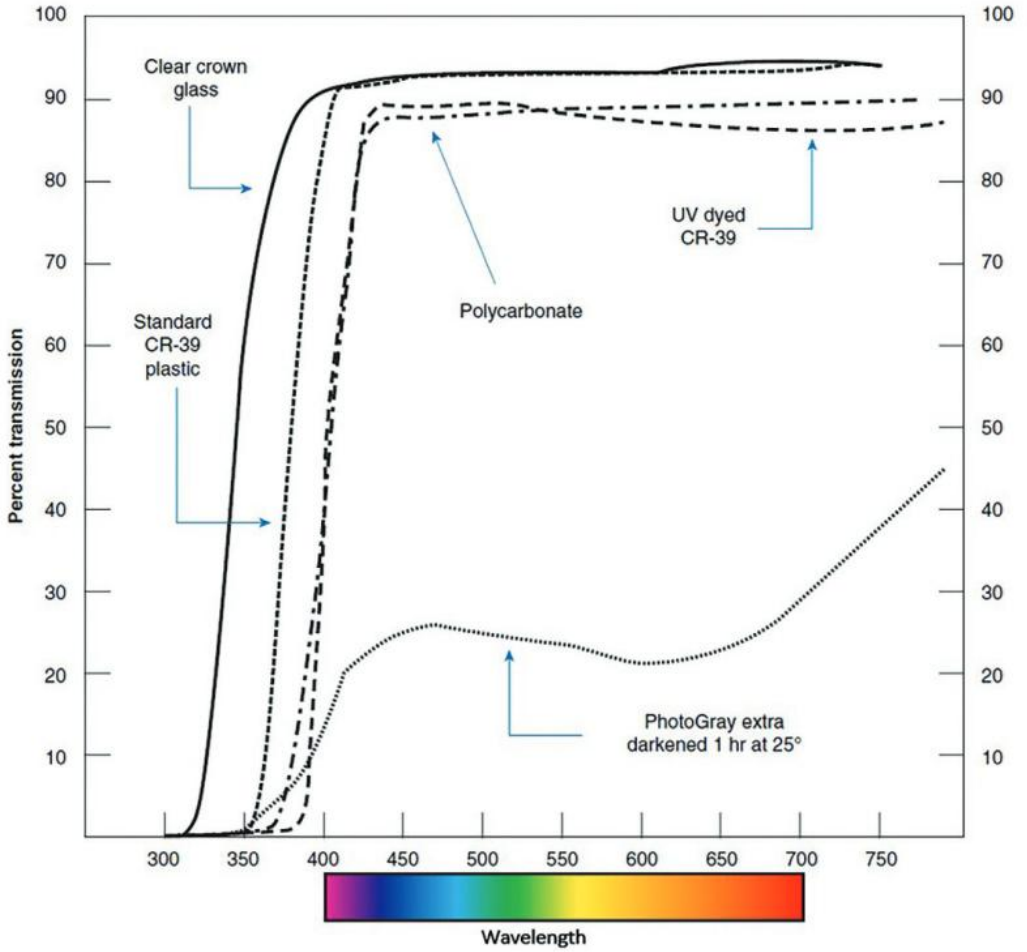


Figure 22.4 Transmission of ultraviolet (*UV*) radiation for standard ophthalmic lens materials. The polycarbonate lens material listed has an antiscratch coating standard for polycarbonate prescription lenses. Polycarbonate lens' UV-blocking properties are a result of the coating on the material and not the material itself. (Transmission curves from *Spectral Transmission of Common Ophthalmic Lens Materials*. St Cloud, Minn: Vision-Ease; 1984:1, 16; from *Photochromic Ophthalmic Lenses, Technical Information*, Publication #OPO-232. Corning, NY: Corning Inc.; 1990:5; and from Pitts DG, Kleinstein RN. *Environmental Vision*. Boston: Butterworth-Heinemann; 1993.)

the literature, Bradley states, "... probably not. Dozens of studies all report the same basic result: visual performance through yellow filters is approximately the same as vision through a spectrally neutral filter with the same absorption, and this is generally slightly worse than with no filter at all. A select few studies have shown that vision through yellow filters is slightly better than vision through transmission-matched spectrally neutral filters, but these studies fail to show that vision through a yellow filter is superior to vision without any filter."[14]

Yellow lenses have been suggested for use in night driving under the premise that they increase nighttime road visibility and reduce oncoming headlight glare. However, a study at the Schepens Eye Research Institute comparing pedestrian detection with and without yellow-lens glasses during night driving with and without headlight glare do not appear to support having eye care professionals advise patients to use yellow-lens night-driving glasses.[15] *Any* tint that cuts down on already dim illumination further reduces visual acuity, offsetting any reduction in headlight glare. The best solution for headlight glare at night is an AR-coated prescription that is up to date. Uncorrected refractive error will cause glare at night. Thus, up-to-date lens prescriptions should be AR coated to further reduce glare caused by reflections within the spectacle lens itself.

In certain daylight circumstances, if the background color surrounding a specific object, such as the blue sky, can be altered by a filter, then it is possible to increase contrast and make the object being viewed easier to perceive.[16] "It has been argued that yellow lenses have the advantage that they selectively darken the bright blue sky without reducing the luminance of green, yellow, and red targets on the ground."[14] For example, yellow lenses are traditionally used in competitive shooting. Many sportsmen believe their shooting ability is improved by a yellow tint. Even so, one of the earliest studies of 136 marksmen done in overcast daylight conditions found that only one individual showed a marked improvement. The author concluded that "the benefit of yellow lenses depends entirely upon the individual; some may be helped while others may be hindered."[17]

Brown

Brown or gray-brown lenses are often used for sun lenses in Germany and other middle-European countries.[18] Brown lenses have some of the same characteristics as yellow lenses in that there is a higher absorption of shorter visible wavelengths (see Figure 22.6). By reducing the transmission of the blue end of the spectrum, brown lenses are sometimes advocated to improve contrast.

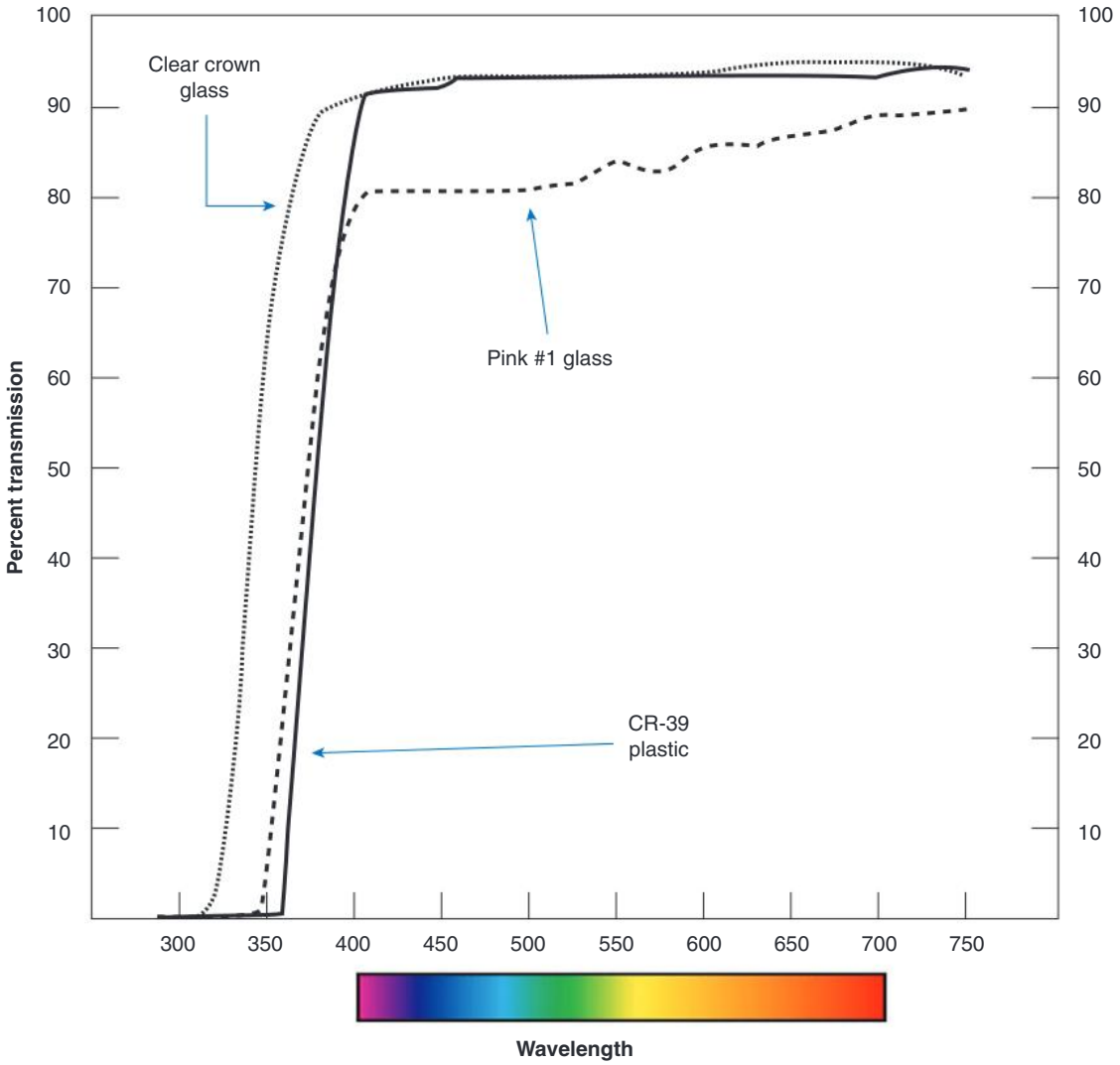


Figure 22.5 Transmission curves for clear crown glass, clear CR-39 plastic, and a #1 crown glass pink tint. Note how closely the transmission curve for the pink matches the curves for the clear. Because the pink has a relatively flat, horizontal curve across the visible spectrum, there should be no disturbance to relative color perception. (From *Spectral Transmission of Common Ophthalmic Lens Materials*. St Cloud, Minn: Vision-Ease; 1984.)

Green

Green sun lenses have a transmission curve that closely approximates the color sensitivity curve of the human eye. They were first made popular through use in the military, were largely replaced by the neutral gray lens, but have been making a limited but noticeable resurgence. The green-tinted glass lens obtains its color and characteristic transmission curve from ferrous (iron) oxide. There is good absorption for the green glass lens in both the IR and UV regions (Figure 22.7). When a lens is vacuum coated to a green tint, the IR absorption is acceptable but not quite as good as the tinted glass lens. Though glass now has limited use in regular spectacle lenses, it continues to have a presence in sunglass lenses.

A plastic lens dyed green to approximately the same shade as its glass counterpart exhibits poor absorption in the IR region. This characteristic is typical for dyed plastic lenses. Most dyed plastic lenses in many different colors do not absorb as well in the long wavelength visible and infrared regions of the spectrum.

Gray

Gray is a popular for sun protection—and with good reason. Perhaps the best aspect of gray is its evenness of transmission through the visible spectrum (Figure 22.8). An even spectral transmission across the visible spectrum allows colors to be seen in their natural state relative to one another. For this reason, neutral gray is quite satisfactory for use by those with color vision deficiencies. Gray lenses will not help a color-defective individual in his or her perception of colors, but neither will it cause further misjudgment of colors as often happens to a color-defective individual when wearing lenses having a transmission that varies across the visible spectrum. Persons with normal color vision are able to adapt to most color changes caused by colored lenses, but people with color vision deficiencies do not have this adaptive ability. When other than neutral gray sunlenses are worn, individuals with color deficiencies may show increased color-judgment errors. This could cause some objects to appear to have unusual or unnatural colors. (For more on lenses for individuals with color

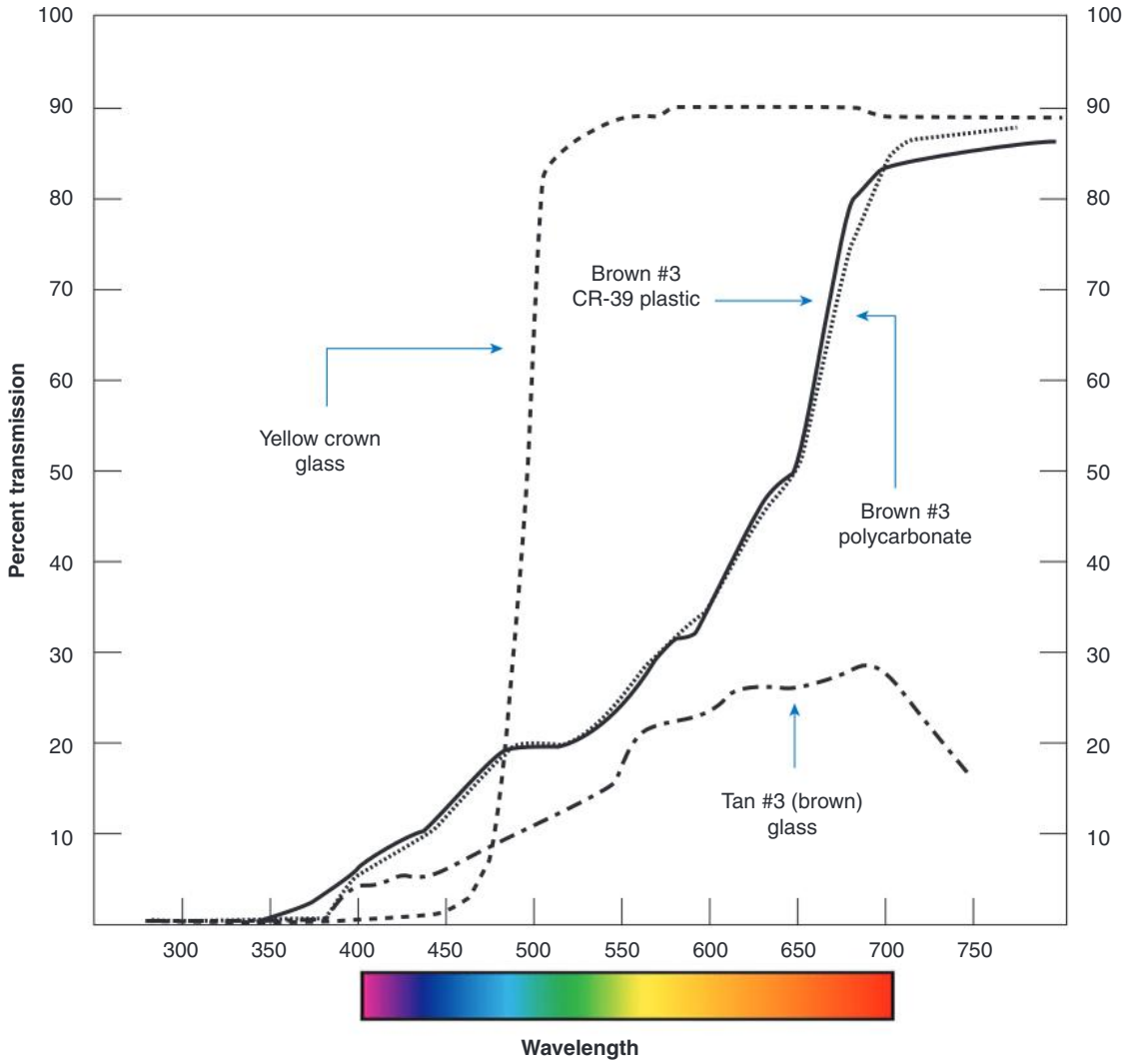


Figure 22.6 Transmission curves for yellow and brown tints. Yellow has a characteristic sudden drop in transmission between 500 and 450 nm. Brown also shows a drop, but that drop is spread over a larger part of the visible spectrum. Note how dyed plastic and polycarbonate lenses transmit the long end of the spectrum, including the infrared. It is possible to use lens dyes that absorb in the infrared region of the spectrum, if desired. (Yellow crown glass and tan #3 [brown] glass transmission curves are redrawn from: *Spectral Transmission of Common Ophthalmic Lens Materials*. St Cloud, Minn: Vision-Ease; 1984:9, 10. Brown #3 CR-39 and polycarbonate transmission curves from Pitts DG, Kleinstein RN. *Environmental Vision*. Boston: Butterworth-Heinemann; 1993.)

deficiencies, see this topic in the Specialty Absorptive Lenses section later in this chapter.)

SUNGLASSES

According to Pitts and Kleinstein,[1] the ideal pair of sunglasses should do the following:

1. Reduce the intensity of sunlight for optimum visual comfort and visual performance.
2. Eliminate parts of the optical spectrum that are not required for vision and are hazardous to the eyes.
3. Provide enough protection while being worn during the day so that the wearer's dark adaptation and night vision are preserved at night.
4. Maintain normal color vision and allow the wearer to distinguish traffic signals quickly and correctly.
5. Resist impact and scratching and only require a minimum of care.

Sunglasses must meet the same impact-resistance requirements as any other spectacle lenses, whether they are for prescription or nonprescription use. The test for normal dress eyewear impact resistance is the ability to withstand the impact of a $^{5}/_{8}$-inch steel ball dropped from 50 inches.

The four categories of sunglass and fashion lenses listed in the ANSI Z80.3–2018 Sunglass and Fashion Eyewear Requirements are listed in Table 22.1. The U.S. Food and Drug Administration (FDA) guidelines for nonprescription sunglass lenses include requirements concerning color based upon these same standards. Color requirements are put in place because of traffic signal recognition needs since individuals with color deficiency can have their perception of color significantly altered by certain tints. People with normal color vision would not

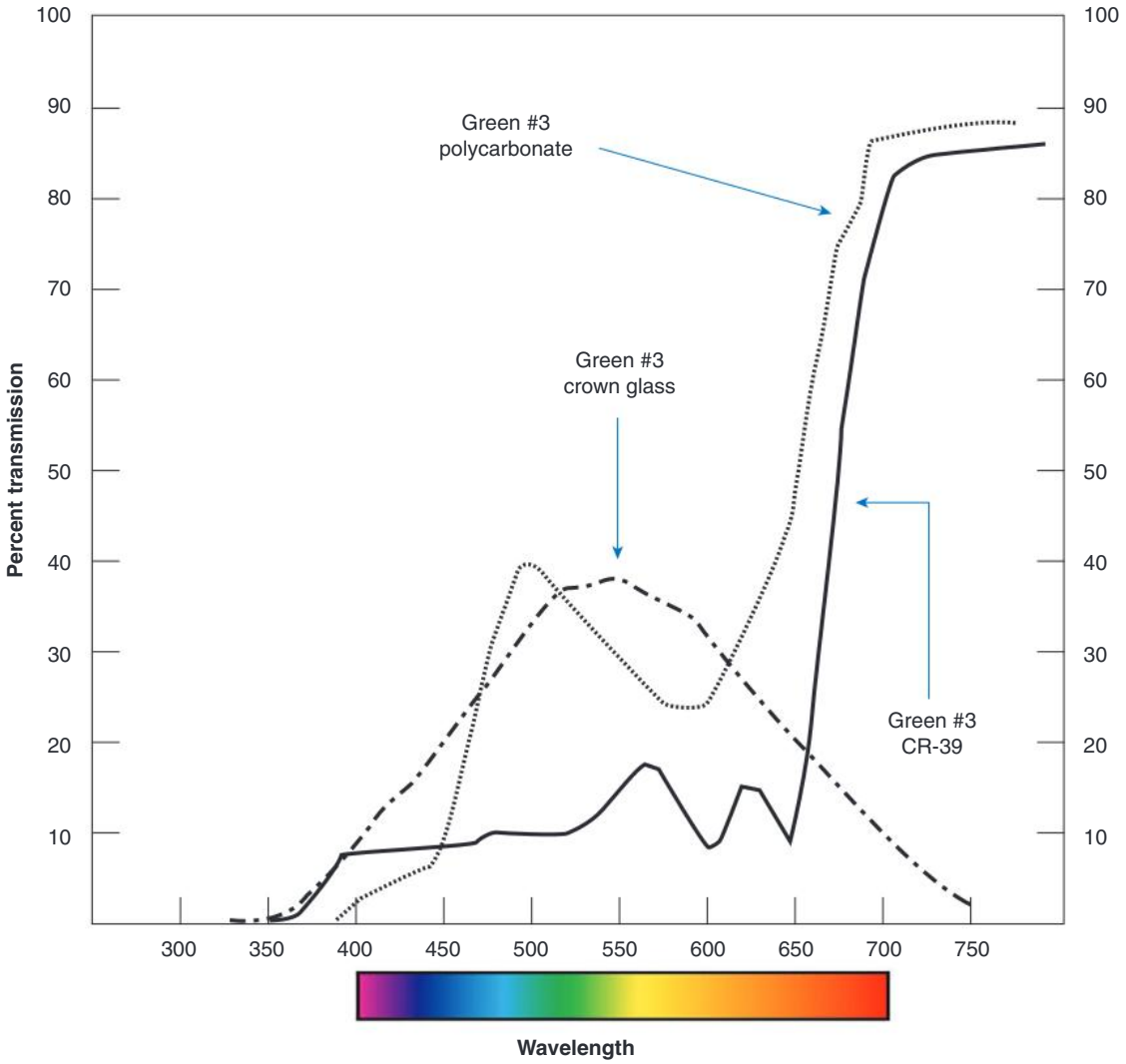


Figure 22.7 Green absorptive lenses have a transmission curve with a characteristic "hill" in the middle of the visible spectrum. Green glass lenses are good ultraviolet and infrared absorbers. Plastic and polycarbonate lenses, however, transmit light in the long visible end and infrared region of the spectrum. This is characteristic for dyed plastic materials in any color unless a specific infrared absorber has been added to the dye. (Transmission curves from *Spectral Transmission of Common Ophthalmic Lens Materials*. St Cloud, Minn: Vision-Ease; 1984, and from Pitts DG, Kleinstein RN. *Environmental Vision*, Boston: Butterworth-Heinemann; 1993.)

necessarily have their ability to discriminate traffic signal colors affected by the same tints that would confuse an individual with a color deficiency. However color confusion for color-normal individuals could be caused by a strongly colored special purpose lens or shield.

Over-the-counter sunglass standards do not apply to prescription sunglass lenses. However, this places a larger burden of responsibility upon the prescriber and dispenser.

For example, Bradley[19] shows that both yellow and brown lenses fail to meet the ANSI Z80.3 (and FDA) standards for nonprescription sunglass lenses. Yet these tints are readily available in prescription eyewear, and brown is a commonly used prescription sunglass lens tint. So whereas such a tint may not make traffic signal colors unrecognizable for a color-normal individual, a color-defective person would not be able to discriminate a red from green traffic light signal adequately.

What does this mean? This means that the dispenser should not knowingly dispense sunglass or fashion lenses to a color-defective individual that would not conform to FDA standards for nonprescription sunglass and fashion eyewear.

DYEING PLASTIC LENSES

CR-39 plastic lenses offer great versatility in tinting since they may be dyed to almost any color and may also be made as light or dark as desired. The clear plastic lens is simply dipped in a dye solution of the desired color. The longer the lens is left in the dye, the darker the tint. As the dye is absorbed over the surface area of the lens, good-quality, well-cured plastic lenses result in a tint of a uniform density independent of lens power and variation in lens thickness. The tint is neither lighter in the thinner portions nor darker in the thicker. Plastic lenses made for materials other than CR-39 may not dye as well.

Gradient Lenses

Gradient lenses have a darker upper portion that gradually lightens toward the lower lens part of the lens (Figure 22.9). A gradient tint is accomplished by immersing the whole lens upside down in the dye. The lens is repeatedly immersed and removed from the solution,

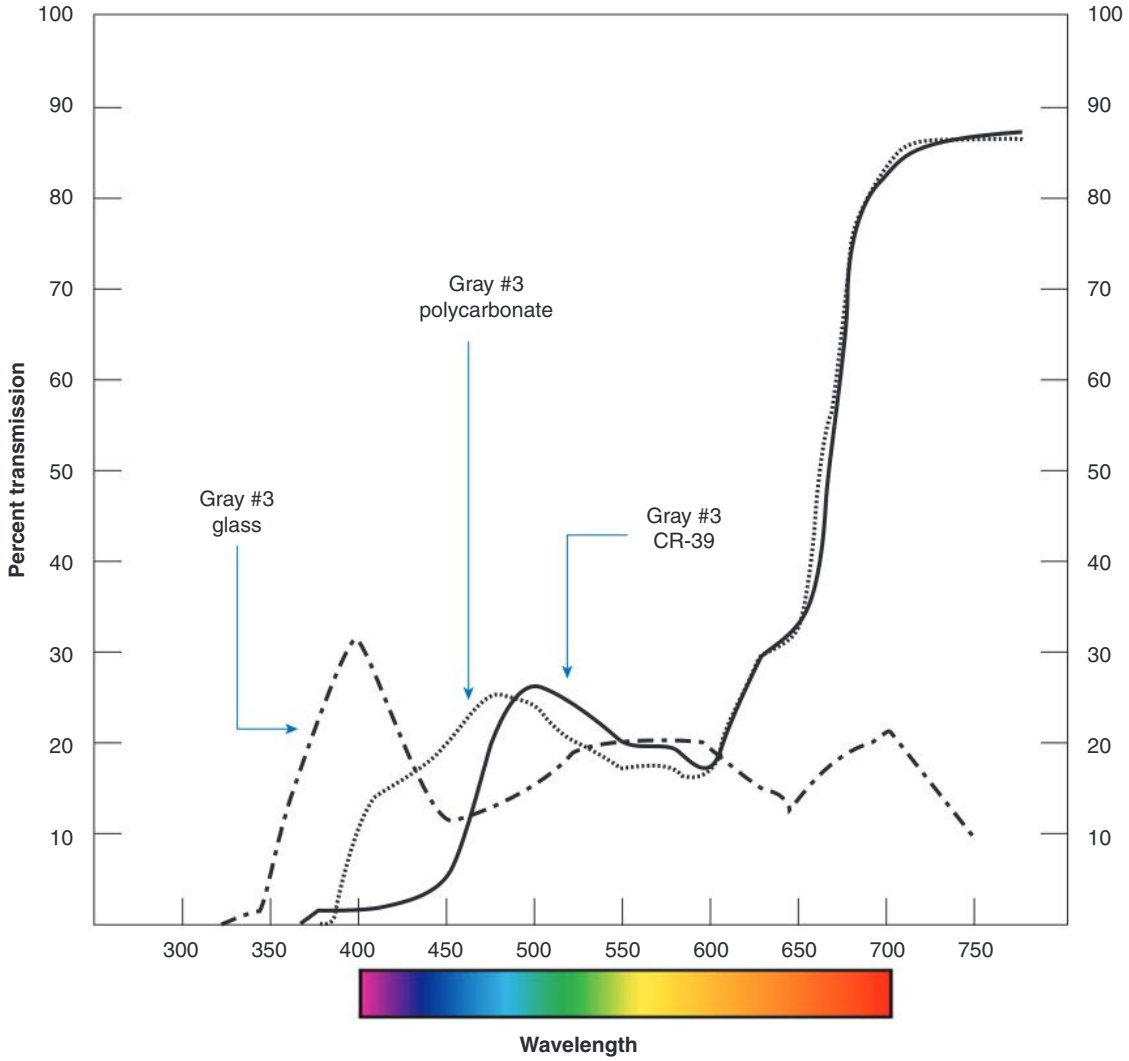


Figure 22.8 In the visible region from approximately 400 to 700 nm, the gray lens gives a fairly even transmission curve, making color perception closer to what would be perceived without absorptive lenses. (Transmission curves from: *Spectral Transmission of Common Ophthalmic Lens Materials*. St Cloud, Minn: Vision-Ease; 1984, and from Pitts DG, Kleinstein RN. *Environmental Vision*, Boston: Butterworth-Heinemann; 1993.)

TABLE 22.1 Nonprescription Sunglass and Fashion Eyewear

Primary Function and Shade	Light Transmittance	Basic Description
A cosmetic lens or shield (light)	Transmission greater than 40%	Generally speaking, this lens is more for fashion than function.
A general-purpose lens or shield (medium to dark)	Transmission between 8% and 40%	This is the category used for sunglasses normally used by most individuals.
A special purpose lens or shield (very dark)	Transmission between 3% and 8%	This lens is appropriate for situations of very intense light, such as for mountain climbing.
A special purpose lens or shield (strongly colored)	Transmission greater than 8%	These lenses, although transmitting more than 8% of light, filter certain spectral colors more heavily than others. This can cause perceived colors to fall outside standard chromaticity limits and interfere with traffic signal color perception

Data from ANSI Z80.3–2018. *American National Standard for Ophthalmics—Nonprescription Sunglasses and Fashion Eyewear—Requirements*, Alexandria, VA: The Vision Council; 2018:25.

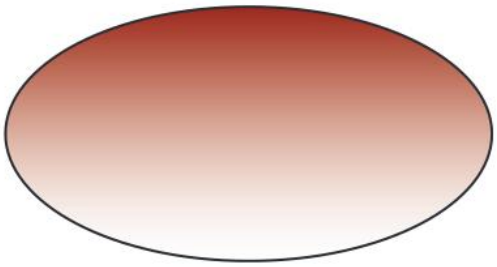


Figure 22.9 A gradient lens varies in transmission over the surface of the lens.

each time to a slightly different level on the lens. The bottom of the lens is in the tinting solution only occasionally, whereas the upper section remains longer, absorbing more of the color.

Changing and Matching Colors

Plastic lenses that have been tinted may be bleached out again and retinted if a tint has proven unsatisfactory as long as they have not been subsequently AR coated. Clear CR-39 plastic lenses may be tinted at any time. For example, when a person decides to change to a new frame, even though the prescription remains unchanged, the old pair may be tinted for fashion or sun wear.

When only one tinted lens is to be replaced, it is not always easy to match the previous tint of the other lens. One method used to create a match between two lenses is to bleach out the old lens and redye it with the new one. Even then, an exact match can be difficult because the lens materials from the two lenses may not take dyes in the same manner. It is much safer to replace both lenses.

Dyeing Polycarbonate and High-Index Lenses

Polycarbonate lenses must be antiscratch coated to be usable for ophthalmic purposes. With polycarbonate lenses, dyeing of the lens occurs within the antiscratch coating. Antiscratch coatings are not uniformly permeable to dyes. Dyeing some of the harder coatings dark enough to reach a sunglass tint may not be possible. There are some scratch-resistant coatings that are made to be tinted. These will dye darker but are not as resistant to scratching as regular semitintable polycarbonate lenses. Polycarbonate lens suppliers have a selection of pretinted polycarbonate lenses. These lenses have a tint within the polycarbonate material itself. The lens can then be further darkened by additional tinting.

High-index plastic lenses dye more slowly than CR-39 lenses and may require special processing. Especially dark tints may not be easy to achieve, depending on the type of material used. It should also be noted that the resulting color of the tint may not be the same for high-index plastics as for a CR-39 sample lens. (Some high-index plastics cannot be dyed at all.) Trivex lenses will dye more rapidly and successfully than other non-CR-39 plastic materials.

LENS COATINGS

Coatings represent an area that can greatly increase wearer satisfaction. Those who educate themselves in the area and can apply that information will find the benefits rewarding.

Scratch-Resistant Coatings

Because of the tendency of plastic lenses to scratch more easily than glass lenses, manufacturers have developed processes of coating the plastic lens to develop more surface hardness and thus more resistance to scratching. Scratch-resistant coatings (SRCs) are also called *antiscratch coatings*, or *hard coatings*. Scratch-resistant coated lenses are not specifically designed to reduce lens reflections but may exhibit some reduction of lens reflections. However, anyone who expects these coatings to noticeably reduce reflections will be disappointed.

Today most eyeglass lenses have already-applied SRCs. With the possible exception of CR-39 material, any extra charges for SRCs are superfluous, since these coatings are expected and already applied. This is especially true for polycarbonate lenses, which cannot be worn without the coating.

Care of Scratch-Resistant–Coated Lenses

Lenses with antiscratch coatings should not be exposed to excessive heat; approximately 200 °F/93°C is a safe upper temperature limit. (Obviously better-quality coatings will do better under stressed conditions.) Therefore, a certain amount of care should be taken when heating the frame for the insertion of lenses. It is not advisable to immerse coated plastic lenses in a hot salt bath. An air blower is the safer alternative to help prevent possible surface crazing. (In fact, there are so many situations where a hot salt or hot beads frame warmer can damage lenses that dispensers should use hot air for frame warming exclusively.)

Damage to the coating of a lens may not appear immediately. At the time, the effect of mistreatment by exposure to intense heat in the dispensary may not make the lens appear any different. With use and exposure to sunlight, heat, and agents in the environment, the weakening initiated in the dispensary may cause the coating to fail at a later date. Most coating failure is reported by the wearer as an inability to clean the lens sufficiently. The wearer will report a film on the lens that no amount of cleaning will remove. On examination the surface of the lens is lightly crazed and may have an oily or lightly frosted appearance. As would be expected, cheaply applied coatings are most subject to failure.

Cleaning Lenses With Scratch-Resistant Coatings

Cleaning instructions for SRC lenses are basically the same as for regular CR-39 lenses. Namely, rinse the front and back surfaces with water to remove small particles. Dry the lenses with a soft, clean cloth or a tissue. Do not wipe the lenses when they are dry. If lenses are to be cleaned dry, the best solution is to use the same type of cleaning cloth as is used for AR-coated lenses.

Note: There is disagreement over whether or not to use tissues on plastic lenses. If the lens surface is dirty and dry, using a dry tissue may cause circular microscratches on a lens surface. If the lens surface has been washed or rinsed clean, drying the lens with a tissue will cause no harm.

Identifying Scratch-Resistant–Coated Lenses

It may be possible to identify an SRC lens by seeing if water beads on the surface as it does on a waxed car. Another test is to mark the surface with a water-soluble marking pen. An antiscratch coating can cause the mark to look streaky or blotchy.[20] These tests may detect most but not all antiscratch coatings successfully. It is almost unnecessary to check for the presence of an SRC since it may generally be presumed that most plastic lenses now come with such a coating. Furthermore, any lens that has an AR coating will have already had an antiscratch coating applied prior to AR coating the lens.

Antireflection Coatings

An AR coating is a thin, transparent layer or layers applied to the surface of a lens. Its purpose is to (1) reduce unwanted reflections from the lens surface and (2) increase the amount of light that passes through the lens.

Lens Reflections Vary According to Index of Refraction

When light strikes the front or back surface of a lens, a percentage of light is reflected from the surface. This light is seen by an observer and could be described as a "window effect," such as light seen reflecting from the surface of a window (Figure 22.10). The amount of light that is reflected is predictable and depends upon the index of refraction of the lens. (See the Absorptive Lens Calculations section at the end of this chapter for more on this subject.) The higher the index of refraction, the more light is reflected. For this reason, those who wear high-index lenses will like their lenses much better with an AR coating that removes these annoying reflections. As can be seen in Table 22.2, a low-index CR-39 plastic lens reflects 7.8% of incoming light, but a high-index plastic lens can reflect 14.1% or almost twice as much. This can have an effect not only on how the lenses look, but also on how they would perform at night with only 85.9% of incoming light being transmitted.

Five Troublesome Lens Reflections

There are basically five reflections that present potentially disturbing reflected images to the wearer's eye (Figure 22.11). These reflections are caused by light coming from an image that does not go directly into the eye but is first reflected from one or more surfaces of the spectacle lens.

Under certain circumstances, a light or object from behind can be seen by the spectacle lens wearer. This situation is shown in Figure 22.11, *A* and *B*. In Figure 22.11, *A*, light is reflected from the back surface of the lens and enters the eye, whereas in Figure 22.11, *B*, light is reflected from the front surface of the lens. For normal spectacle-lens wearers, this is most noticeable at night when illumination is low, and there is a bright source of light from behind. For those wearing sunglasses, reflections from behind will be visible during the day. This is because the image illustrated in Figure 22.11, *A* will not be attenuated by the dark sunglass lens as are objects in front of the wearer viewed through the lens.

A B

Figure 22.10 AR coating removes the "window effect" by extinguishing reflections from the lenses, as seen here in photos comparing how rimless lenses look without **(A)** and with **(B)** an AR coating. (From Zeiss ET. *Coatings-Product Facts,* Publication MI 9054–1198. Carl Zeiss.)

The reflected images illustrated in Figure 22.11, *C* through *E* will appear as "ghosts" of objects viewed through the front of the lens. They are much less intense than the object itself but, under certain conditions, are readily noticeable. Ghost images can be most easily seen at night by looking at a source of light such as a street light. By turning the head while still looking at the street light, it is often possible to see one or more "ghosts" of the light trailing off to one side. These ghost images are caused by the reflections illustrated in Figure 22.11, *C* through *E*.

In addition to reflections seen by the wearer, there are reflections of light sources and other objects seen reflected from the lens surface by an observer. Regardless of source, all reflections are reduced considerably by AR coatings.

A person may request a tint for indoor glare conditions when he or she would be better served by an AR coating. Although a tint may help somewhat, an AR coating is superior. It will be noted that, in Figure 22.11, all but one of the troublesome reflections travel through the lens at least once. The reflected images are therefore reduced by a light tint within the lens, but they are not reduced as much as they would be with an AR coating.

The Theory of Antireflection Coatings

According to optical theory, for a single-layer AR coating to reduce reflections, an AR coating must meet two conditions: the *path condition* and the *amplitude condition*.

The path condition. Very simply stated, the path condition determines what the optical thickness of a single-layer coating film must be. To achieve the desired effect, the film must be either one-fourth of a wavelength thick or odd multiples of one-fourth of a wavelength (i.e., one-fourth, three-fourths, five-fourths, and so forth). As light strikes a single-layer-coated lens surface, some of the light will reflect from the outer surface of the coating and some from the lens surface (Figure 22.12). This means the two reflected waves of light will be out of phase with each other, causing destructive interference and preventing reflection (Figure 22.13).

The amplitude condition. The amplitude condition requires that the amplitude of the light waves in the lens material and in the film be equal. This is required so that the destructive interference of the two reflected waves will be complete, as shown in Figure 22.13 in which the two sine waves combine to form the zeroed-out straight line. The distance from the top to the bottom of the wave must be the same. This can be achieved by controlling the index of refraction of the film. The relationship between the index of refraction of the lens material and the film coating must be:

$$n_{film} = \sqrt{n_{lens}}$$

TABLE 22.2 How Surface Reflections Vary According To Lens Refractive Index

Lens Material	Refractive Index	Percent Reflection From Front Surface	Percent Reflection From Back Surface	Total Percent Reflected From Both Surfaces	Total Percent of Light Transmitted
CR-39 plastic	1.498	3.98%	3.82%	7.8%	92.2%
Crown glass	1.523	4.30%	4.11%	8.4%	91.6%
Polycarbonate	1.586	5.13%	4.87%	10.0%	90.0%
A high-index plastic lens	1.66	6.16%	5.78%	12.0%	88.0%
A higher-index plastic lens	1.74	7.29%	6.76%	14.1%	85.9%

It should be noted that these figures are for light entering the lens from the straight-ahead position. Light striking the lens at an angle will be reflected slightly more.

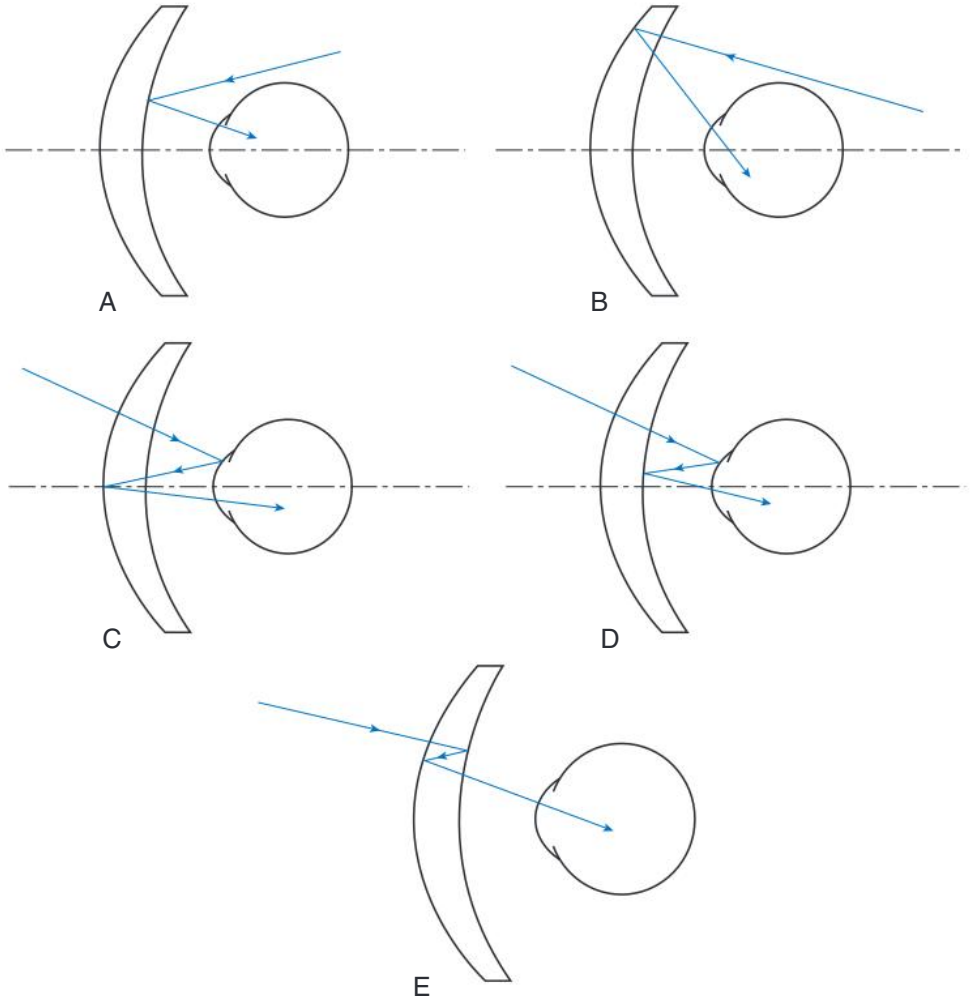


Figure 22.11 Five reflections of spectacle lenses that may prove troublesome to the wearer. It is possible to lessen the effect of reflections **B**, **C**, and **E** with a tinted lens. However, all reflections are virtually eliminated using an antireflection lens coating. A coated lens is the method of choice for reducing lens reflections rather than the use of a light lens tint. (From Rayton WB. The reflected images in spectacle lenses, *J Optical Soc Amer* 1917;1:148.)

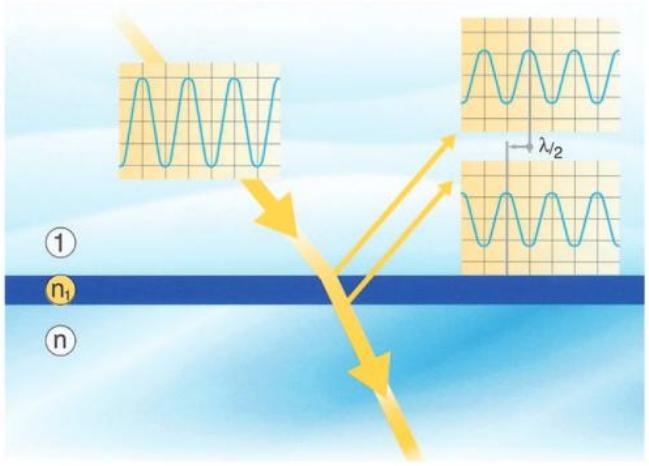


Figure 22.12 When light strikes a surface with a single-layer AR coating having the correct thickness, the reflected light from the two surfaces will be one half wavelength out of phase. (From *Coatings, Ophthalmic Lens Files*, Paris: Essilor International; 1997.)

The index of the film must be equal to the square root of the index of the material being coated. This relationship is derived from reflection factors (ρ) between air and film

$$\rho_1 = \left[\frac{n_F - 1}{n_F + 1}\right]^2$$

and between film and lens.

$$\rho_2 = \left[\frac{n_L - n_F}{n_L + n_F}\right]^2$$

The reflection factors must be equal for the amplitude condition to be fulfilled. In other words,

$$\left[\frac{n_F - 1}{n_F + 1}\right]^2 = \left[\frac{n_L - n_F}{n_L + n_F}\right]^2$$

which reduces to

$$n_F = \sqrt{n_L}$$

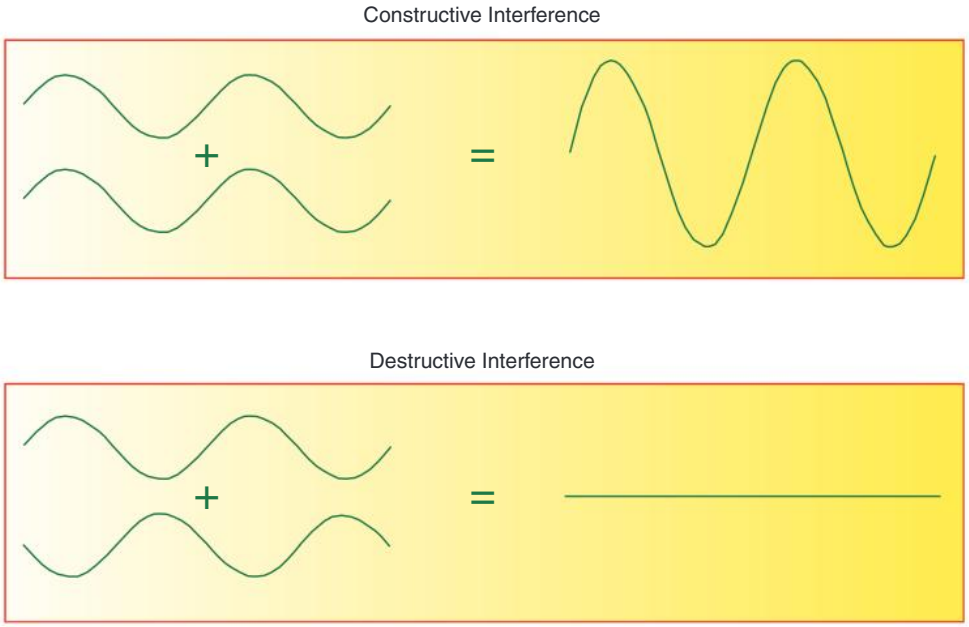


Figure 22.13 Two waves of light that are exactly in phase with each other, as seen at the top left, will constructively interfere with each other. The resulting amplitude of the combined light is enhanced as seen at the top right. Two waves of light that are out of phase, as seen on the lower left, will destructively interfere with each other and when added together are extinguished, as shown by the line on the right.

Example 22.1

What would the ideal refractive index be for a single-layer AR coating applied to a high-index lens if the lens has an index of refraction of 1.6?

Solution

Since the lens has an index of refraction of 1.6, the ideal index of the single-layer AR coating would be the square root of 1.6.

$$\begin{aligned} n_F &= \sqrt{n_L} \\ &= \sqrt{1.6} \\ &= 1.265 \end{aligned}$$

Therefore, the ideal single-layer AR coating would have an index of refraction of 1.265.

Why single-layer antireflection coatings are not 100% effective. If both the amplitude and path conditions are exactly fulfilled for every wavelength, there would be minimal reflections from the lens with close to 100% of light passing through to the eye. This is not the case, however, because of limitations in available coating materials that are both hard enough and of the proper refractive index.

Another reason why single-layer AR coatings are not 100% effective is because the correct coating thickness for yellow light, which falls in the center of the visible spectrum, is not the correct thickness for blue and red light, which fall at either ends of the visible spectrum. This is the reason why, for certain angles of viewing, single-layer AR-coated lenses have a purplish cast. Since yellow light is found at the approximate midpoint of the visible spectrum and is also the color to which the eye is most sensitive, it has been chosen as the optimum wavelength for which the conditions should be fulfilled. For that reason red and blue, which have longer and shorter wavelengths than yellow, do not fulfill these conditions as well. They are reflected more than the yellow. Red and blue reflections combine to give a bluish-purple cast to a single-layer AR-coated lens.

Initially, AR coatings were only available as single-layer coatings. This posed certain limitations on the effectiveness of the coating. Now that multilayer coatings are the norm, AR-coated lenses are more attractive, more efficient, more scratch resistant, and considerably easier to clean.

Multilayer-Coated Lenses

From an optical point of view, using more than one layer helps to solve the problem of a single-layer coating that is ideal only for yellow light. Stated in oversimplified terms, if another layer of a different specifically determined refractive index is added, more of the remaining light that would otherwise be reflected is allowed to pass through; if a third layer is added, even more light would pass through. If a lens is coated properly, a large percentage of the reflected light is now allowed to pass through the lens, but the optical aspects of a multilayer coating are only a part of the purpose for multiple layers.

A typical multilayer-coated lens is not placed directly on the lens. The lens is first coated with a primer, then hard coated. This hard coating is basically an antiscratch coating. The next layer is chosen to provide maximal adhesion between the hard coating and the AR coating. The AR coating is applied as more than one layer; sometimes alternating layers of high and low refractive index.[21] Efficiency is not directly related to the number of layers used. The AR coating is then sealed in with a hydrophobic (water-repelling) top coat (Figure 22.14). Many newer coatings are so efficient in repelling water and oil-based smudges that the slippery surface requires a special lens edging disc. Otherwise the lens slips and/or rotates off-axis during edging.

The relationship between antireflection and scratch-resistant coatings. AR coatings will adhere to a lens *better* if the lens has a high-quality antiscratch coating. Antiscratch coatings are now considered essential for good adherence of the coating and reduction in damage to the coating.

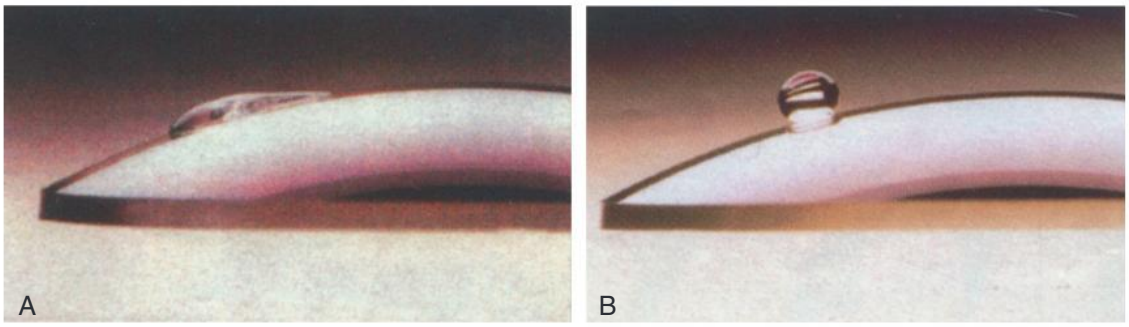


Figure 22.14 Lens **A** does not have a water-repelling top coat, and the water droplet spreads out on the lens. Lens **B** has a hydrophobic coating **which** causes water to bead up and slide off more easily, keeping the lens cleaner. (From Bruneni J. *AR and Other Thin Film Coatings,* Eyecare Business; July, 2000:5.)

Here is an analogy that describes how an antiscratch coating supports the AR coating: "AR coatings are hard and brittle. By comparison, plastic lenses are soft and spongy. Think of a single paper tissue (representing the AR coating) lying on a soft feather pillow (representing the lens). If you poke your finger at the tissue it easily rips. If you place a single tissue on a hard desk and try poking it with your finger, the tissue remains intact and undamaged. The analogy holds with AR coated lenses. The organic hard coat (over the lens and under the AR coating) supports the thin brittle AR coating much as the hard desk supports the paper tissue."[22] This explains why AR coatings were successful on glass lenses before they were on plastic lenses. Glass is a very hard substrate and an excellent support for the thin, brittle AR coating layers.

Note that AR coating should not be applied after lenses have been worn. This is because even small, unseen scratches will become visible after AR coating is applied.

Matching the antireflection coating to the substrate. The best way to be sure that an AR coating will perform well is to engineer it for the material upon which it will be placed. The basic lens material is chosen, such as ordinary CR-39. Then a primer and hard coating are selected that will work well with both the lens and the AR coating. The lens is sold with the coating already on it.

However, for other than single-vision lenses, this may not be able to be controlled as well. There are a large number of variables. This is especially true in the U.S. market in which there is a diversity of wholesale optical laboratories supplying different brands of lenses made from a variety of lens materials. A semifinished lens may come with one type of antiscratch coating already on the front surface. The optical laboratory applies another type of antiscratch coating to the back of the lens after surfacing. Now the coating laboratory must apply an AR coating to both surfaces, having it stick to both surfaces and perform well. Best results are possible if these variables are known.

To overcome the diversity of lens materials and hard coatings, manufacturers have addressed the problem in a number of ways. Here are some:

- By developing a special scratch coating that "can be applied to any non-glass lens, whether the lens is already scratch coated or not."[22] This provides a known uniform base upon which an AR coating can be applied so that inequities from chemical and physical differences in factory-applied and lab-applied coatings can be eliminated.
- Another approach is to totally strip the existing lens of the existing scratch coating and begin again on the base lens material.
- Others do not apply their coating to any lens that they have not manufactured themselves. This avoids contamination that can affect coating quality on a large number of lenses being processed in the coating laboratory.

Impact resistance and antireflection coating. When a plastic lens is coated, the impact resistance normally decreases. (For more on this topic, see Chapter 23.) However, by engineering the coating specially for the material, some high-index plastic lenses are able to be made with 1.0-mm center thicknesses and still pass the FDA drop ball test because the lenses have a special "cushioned" scratch coating that absorbs shock.[23]

Reflex Colors

Multilayer AR coatings do not have the old purplish cast so characteristic of single-layer lens coatings. Instead most have a blue, green, or blue-green appearance. Reflex color is not an indication of coating quality. However, if the lens has a reflex color that changes from one section of the lens to another, that is an indication of an unevenly applied coating. Reflected color "can be tuned by adjusting the layer thickness in the multilayer AR stack."[24]

It is possible to cause a coating to have any one of a range of different reflex colors, including practically no color, and still be an efficient coating.

Antireflection Coating of Already-Tinted Lenses

Lenses that have already been tinted may also be AR coated. However, once a dyed plastic lens has been AR coated, it cannot be either bleached to a lighter color or redyed to a darker color unless the AR coating is first stripped from the lens.

Antireflection coatings make lightly tinted lenses more acceptable at night. If a person desires a light tint but there is a concern that night vision might be affected, an AR coating can return a lightly tinted lens to its previous nontinted transmission. For example, a light tint may reduce lens transmission for a CR-39 lens from the normal uncoated 92% transmission to an 88% transmission. By eliminating front and back surface reflections, AR coating the lens will bring the transmission up to about 95% transmission—better than the transmission in the uncoated state. For night driving, any reduction in illumination will result in a loss of acuity.

If a specific tint transmission is required. If a dyed plastic lens is to be AR coated, it must first be dyed 10% to 15% darker than the transmission desired, then bleached back to the intended tint. This ensures that lens color is buried deeper in the lens. Because of the intense cleaning process used in AR coating, some of the tint near the surface of the lens will be removed. Tinting the lens darker and then removing some of the tint near the surface with neutralizer ahead of time prevents the 5% to 7% lightening that will otherwise occur during the cleaning process.

Unfortunately, at present writing, the application of an AR coating may occasionally change the existing color of tints. The color may lighten, shift in hue, or become unmatched in the application process. These effects are unpredictable as to exactly how and when they will occur.[25]

Antireflection coating of sunglasses. AR coating of sun lenses reduces mirrorlike reflections from the back surface. Sun lenses may be AR coated to advantage. For example, the wearer may find reflections from the back surface of the sun lens disturbing. This is a genuine complaint because of the brightness of purely reflected light coming from behind, contrasted to the darkened image of the object being viewed through the sun lens. (See Figure 22.11, *A,* showing this reflection.) An AR coating allows the majority of light coming from behind the wearer to pass on through the lens without being reflected back into the eye.

Opinion on whether to AR coat the front of the lens is mixed. Some say that an AR coating on the front surface of the lens is not recommended because, when combined with the color of the sun lens, the AR coating leaves an objectionable residual color.[26] However, when residual color can be controlled, then the recommendation is to coat both surfaces because "light is also reflected at a lower intensity at the back side of the front surface... [and]... will give sunglass customers peak performance and the greatest comfort."[27]

Antireflection coating of photochromics. A photochromic lens may be AR coated. AR coating of photochromics will increase both the maximum *and* the minimum transmission by a certain amount. The lens will transmit more light in both the lightened and the darkened state. Normally *color* coatings are applied to the *rear surface* of a photochromic lens. Added front surface tints can cut out many of the rays that activate the lens-darkening mechanism. Color coating is seldom necessary, however, because there are a variety of photochromic colors already available from the photochromic lens manufacturer, and photochromic lens manufacturers offer several striking flash mirror coatings for their own brand of lenses.

Pros and Cons of Antireflection Coatings

The *pros* of an AR-coated lens are both subjective ones noticed by the wearer and objective ones seen by an observer.

Pros. Subjective advantages noticed by the wearer include better light transmission, decreased glare, and improved night vision. There is also a loss of the star-like flare from self-illuminated objects such as headlights, tail lights, and street lamps (Figure 22.15), resulting in better visual performance at night.[28] For progressive addition lens wearers, the distracting "tails" that appear on illuminated digital dashboard accessories are also reduced.

Objective advantages include the loss of surface lens reflections. Without lens reflections, the wearer's eyes become more visible (see Figure 22.10). Because edge reflections are reduced and the lens appears less visible, AR coatings make thick lenses appear thinner.

What used to be the biggest *con* for AR-coated lenses can now be a *pro*. That has to do with cleaning of the lenses. Because the single or multilayer AR coating only works if it is the first thing that light strikes when entering the lens, any dirt, water, or skin oils will reduce the effectiveness of the coating. What this means is that a very small smudge on an AR-coated lens will be much more visible to the wearer unless the AR coating is treated to resist these. This is because the smudge will not only be visible in and of itself, but because the AR coating will not work there, reducing light transmission through the smudge by approximately 4%. Recognizing this, AR developers have worked hard to make their lenses much more cleanable. They have accomplished this with the addition of a hydrophobic top coat that repels water (see Figure 22.14) and oleophobic qualities that repel oils. In fact, these top coatings are so good at repelling water and oils that they are not able to be marked with a normal marking pen. Instead they are best marked with a marker sold through an optical supply resource specifically for this purpose.

Premium AR lenses also have antistatic properties. With antistatic properties, AR-coated lenses will repel rather than attract dust particles, again keeping the lenses cleaner. (No more dryer-type static cling problems.)

Because of hydrophobic, oleophobic, and antistatic properties, premium AR coatings make these lenses much easier to clean than an uncoated lens.

A large *pro* for AR coatings are that, given the choice of a good coating or no coating, studies are showing that people are choosing the AR-coated lenses by a wide margin.[28,29]

Cons. So a high-end AR-coated lens has virtually eliminated their main drawback, which were cleaning problems. Thus the only drawbacks now is the increased lens cost and the damage that may be caused by improper care, which is addressed next.

Caring for an Antireflection-Coated Lens

AR coatings are much tougher than they used to be. They are not, however, as tough as the surface of a normal spectacle lens. Certain precautions need to be taken to keep them in good condition. They include the following:

1. Avoid using ultrasonic cleaners.
2. Avoid salt or bead frame warmers.
3. Avoid excessive heat. (This includes the interior of hot automobiles.)
4. Avoid caustic chemicals and sprays such as acetone, ammonia, chlorine, hair spray, and other aerosols.
5. Avoid marking lenses with heavy inks.

There are ways to correctly clean lenses, and there are cleaning procedures that should be avoided. Lenses should be cleaned at least once a day.

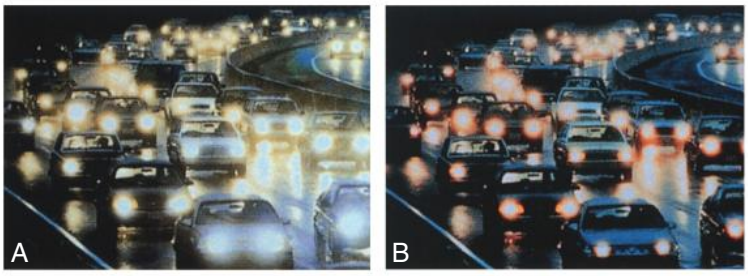


Figure 22.15 Night driving is where many experience a notable difference between uncoated (**A**) and antireflection-coated (**B**) lenses. (From Zeiss ET. *Coatings-Product Facts,* Publication MI 9054–1198. Carl Zeiss.)

Correct Ways to Clean Antireflection-Coated Lenses

Here is a simple sequence for cleaning AR-coated lenses without using a cleaner specifically made for AR-coated lenses[30]:

1. Rinse the lenses with lukewarm water.
2. Clean using a mild dishwashing liquid or hand soap. Soap should not contain a hand cream. That will cause the lenses to smear. Rub soap on both sides of the lens for about 5 s. (It is helpful to wash both lenses and frames at the same time.)
3. Rinse the soap off with tap water.
4. Dry with a soft, clean cloth such as a cotton towel.

Naturally a cleaner designed specifically for cleaning AR-coated lenses will give excellent results. From time to time, it is still worthwhile to use a soap or detergent on both frames and lenses, with lots of running water, to keep the frames clean, too.

There are soft microfiber cloths specifically made for use with AR-coated lenses that allow the lens to be cleaned dry. These work very well for throughout the day and are especially handy when there is no soap and water available. These cleaning cloths should be washed periodically with laundry soap and water, but do not use fabric softener.[31] If cleaning cloths are not washed regularly, they will accumulate oils and dirt particles, especially if kept unprotected in pockets or purses. The accumulated oils can reapply smudges to the lens and the particles will cause microscratches of the coated surface.

Things to Avoid When Cleaning Antireflection-Coated Lenses

Avoid antifog agents that are not specifically marked as being okay to use with AR-coated lenses.

As with any lens, AR-coated lenses should not be exposed to household spray cleaners, chemicals, ammonia, chlorine, and hair spray.[31]

Avoid detergents with citrus, creams, abrasive material, or acetones.

Avoid using an ultrasonic cleaning system. If the frames need deep cleaning with an ultrasonic unit, remove the lenses first.

Antifog Coatings

Antifog coatings are used for individuals who are constantly going into and out of changing temperature environments, who must wear surgical masks, or who are exposed to other environmental conditions that would fog lenses. Wearers who may appreciate antifog coatings include cooks, ice skaters, and snow skiers. Antifog coatings may be applied to existing lenses on a temporary basis or can be made as permanent coatings applied directly to the lens during manufacture. Permanent coatings may be applied to the back side or to both sides. Coatings applied only to the back side are more appropriate for those wearing a breathing mask in which the problem with fog is the back side of the lens. If applied to the back side only, the front side has an AR coating.[32] Individuals who go in and out of cold environments where both sides of the lenses fog up are better served with an antifog coating applied to both sides.

Some permanent coatings require periodic activation with a treated cloth or spray.

Antifog treatments work against the small water droplets that cause light to scatter and fog the lens surface. These droplets have a high contact angle with the lens surface. They bead up the water. In other words, the surface is hydrophobic. An antifog treatment lowers the contact angle, spreading the water out so that it forms a thin layer that can be seen through.[33] Now the surface is hydrophilic.

For existing lenses that do not have a permanent antifog coating, there are nonpermanent antifog agents available. These come as drops, sprays, or wipes. Wipes are either single-use tissues or multiuse cloths. Treatment must be repeated at intervals, depending upon how often glasses are cleaned, which antifog product is being used, and environmental conditions of use. There are many products available and, as would be expected, their effectiveness varies. If the lenses have an antireflective coating, it is prudent to check for compatibility. (Some antifog treatments make AR coated lenses difficult to clean.) AR coatings are hydrophobic. The antifog treatment must be able to grip the slick hydrophobic surface of the AR-coated lens, rendering the lens surface hydrophilic without damaging the AR coating.

Color Coatings

An absorptive coating may be added to a lens through the use of a metallic oxide applied to the lens in a vacuum. There are several advantages to these coatings.

- Color coatings are uniform in transmission. The center has the same darkness as the edge. Yet they can be made as a gradient, with the top darker, fading lighter toward the bottom of the lens.
- The transmission curve of a color-coated lens is smoother across the visible spectrum, being more even than either internally tinted glass or dyed plastic.
- These coatings do not increase in transmission in the near-infrared region but continue absorbing the longer wavelengths in roughly the same proportion as they do in the visible spectrum.
- Color coatings are more durable and can be cleaned easier because of the same advancing technology used for AR coatings.
- Color coating may be applied to most any lens material, from glass to high-index plastic.

Mirror Coating

A mirror coating can be applied by a vacuum process to the front surface of the lens, causing the lens to have the same properties as a two-way mirror. When applied as a full-mirror coating, the observer is unable to see the wearer's eyes and sees his or her own image reflected from the lens. The wearer is able to look through the lens normally. There is, of course, a reduction in the transmission of the lens simply because of the high percentage of light reflected.

Mirror coatings alone do not reduce the amount of light coming through the lens to the level of regular sunglasses but may be used in combination with a tinted lens to provide more protection from intense sunlight than the mirror coating alone can provide.

A *flash mirror coating* or simply *flash coating* is one that may have only a hint of reflectance. Flash mirrors are often used in conjunction with photochromic lenses. In the lightened state the lens has a very light tint with a light reflectance. The reflex color of the flash coating is chosen to compliment the color of the darkening photochromic lens. As the lens darkens, the observer sees less and less of the wearer's eyes and more and more reflection. To the observer this works in the same way as when looking at a window from the inside at night. The window looks like a colored mirror and nothing outside the window is visible.

Edge Coating

Lenses may be edge coated to reduce lens edge visibility. The idea of edge coating is to apply a color to the bevel area of a lens that matches the frame, camouflaging the edge. Often, edge coatings look odd. This is because they are usually applied with a small brush, then hardened in an oven. If the job is not done well, if an inappropriate frame is chosen, or if the color match is poor, the net effect can be worse than no coating at all.

There are many suitable alternatives to edge coatings. These include:

- AR coating the lens, which eliminates concentric ring edge reflection
- Using a lens of higher refractive index to reduce edge thickness

- Using an edge-bevel design that has the effect of reducing thick-edge appearance
- Polishing the edge of the lens
- Using any combination of the above

PHOTOCHROMIC LENSES

A major breakthrough in the area of absorptive lenses took place in 1964[34] with the invention of Corning's PhotoGray glass photochromic lens. A photochromic lens changes in its transmission when exposed to light.

Glass Photochromic Lenses

For glass lenses, the darkening process occurs as a result of silver halide crystals within the glass that are activated by UV and short visible radiation of wavelengths between 300 and 400 nm.

The photochromic process is similar to that which takes place when light strikes photographic film emulsions, also containing silver halide crystals. With the crystals "trapped" in the glass, however, the darkening process is reversible. The glass photochromic lens will not wear out with repeated darkening and lightening cycles, although over time the lenses do not lighten indoors like they do when new.

Plastic Photochromic Lenses

Photochromic lenses are now almost exclusively plastic. Instead of using an inorganic material, such as the silver halide crystals used for glass lenses, plastic photochromic lenses use organic dyes.

Photochromic Lenses and Ultraviolet Light

Although photochromics are more able to perform like a sun lens in their darkened state, they still are not able to replace sunglass lenses in all circumstances. The primary reason for why they do not function as efficiently as a sun lens is that they are unable to darken well behind the windshield of a car. Although a full-range photochromic lens darkens in response to both UV and short-wavelength visible light, because a person driving a car is shaded from direct sunlight and shielded from much UV radiation by the windshield, the lens will not fully darken in normal driving conditions. Those wanting photochromic lenses should be informed that unless the lens is specifically designed for driving, it will not darken deeply enough. The upside to all of this is that since photochromic lenses use UV light in their activation process they are good UV absorbers and therefore provide UV protection to the eyes.

Factors Influencing Photochromic Lens Performance

Light Intensity

Although exposure to UV radiation is the condition that most influences photochromic lens transmission, several other factors contribute to lightening and darkening. A photochromic lens is made to return to its lighter state by exposure to red light or IR radiation. This is referred to as *optical bleaching.*

Temperature

Heat will also bleach the lens. This is referred to as *thermal bleaching.* As a consequence, photochromic lenses do not darken as much on hot days as they do on cold days. On very cold days, photochromic lenses can become extremely dark.

Types of Photochromic Lenses

Standard Photochromic Lenses

Standard photochromic lenses are essentially clear when worn indoors. Outdoors, these lenses darken down to sunglass transmissions. With continued development, standard photochromic lenses continue to shorten the darkening and lightening times required to reach maximum and minimum transmissions. They are much less sensitive to lens aging and loss of performance than earlier photochromic versions.

Photochromic Lenses That Darken More

These are photochromic lenses that are intended for those who are very light sensitive. As an example, the Transitions brand name for this lens type is called *Xtractive.* These lenses are not completely clear when worn indoors but come close to it. This is because they are activated by both UV and visible light. They do achieve greater darkness outdoors than do standard photochromic lenses, including on hot days. When fully activated, their maximum darkness is greater than for standard photochromic lenses. In the car, they do not darken to a full sun lens tint, although they darken more than standard photochromic lenses.

Photochromic Lenses With Polarization

When photochromic lenses include polarization, that polarizing ability starts low and increases as the lenses darken. When polarization is part of an Xtractive lens, polarization is fully functional outdoors. This is a great advantage around water or snow. Unfortunately, polarization is not activated sufficiently behind the windshield of a car to allow it to replace conventionally polarizing sun lenses intended for driving.

Photochromic Lenses Intended for Driving

Polarization makes lenses better for driving because polarization blocks reflected road glare. A conventional polarizing lens is not like the photochromic polarizing lens just described above but polarizes light in any wearing situation, with or without UV light. A conventionally polarizing material can be incorporated into any lens, including a photochromic lens. However, it cannot be made as a clear lens but will have a noticeable tint indoors or outdoors.

That being said, a photochromic lens using conventional polarization can be made for driving. The lens currently available is the Younger Optics Transitions Drivewear lens that combines a conventional-type polarizing filter with tinted photochromic material activated by both UV and visible light. The photochromic material used causes the lens to appear yellow/green in its lightest state. When inside a car, the lens is darkened by visible light coming through the windshield causing it to take on a copper appearance. When worn outside of the car on a bright day, it is further activated by UV light resulting in a dark reddish-brown color.

Colors for Photochromic Lenses

The two most common colors for photochromic lenses are gray and brown. However, photochromic lenses are made in a variety of colors. Most photochromic lenses begin with one color and change to a darker shade of that same color. Yet it is possible to make a photochromic lens that starts with one color in the lightened state and darkens to a different color. The colors available will vary by manufacturer.

One of the interesting photochromic examples of color possibilities is created using a flash mirror coating on photochromic lenses. A flash mirror allows the lenses to start out with a minimally-mirrored hint of color, then darken down to a uniquely colored mirror lens. Such flash coatings may be applied to most any type of photochromic lens. (Flash coatings were just discussed in the previous section on mirror coatings.)

POLARIZING LENSES

Glare from reflecting surfaces is one problem that is only partially alleviated by regular absorptive lenses. Glare is commonly caused by reflections from water, snow, highways, and metallic surfaces.

A normal absorptive lens reduces the intensity of light evenly, which also reduces reflected glare. Yet a normal absorptive lens leaves the glare at the same level relative to the surroundings as it was before. Light reflected from a smooth, nondiffusing surface is peculiar in that for the most part it has been *polarized* through the reflection process.

How Polarizing Lenses Work

Ocean waves vibrate up and down as they travel, as is evidenced by the up-and-down motion of a floating cork. A light wave is not so restricted and is free to vibrate up and down, sideways, or obliquely. In other words, in their nonpolarized state, light waves vibrate perpendicular to the direction in which the light is traveling but with no particular degree orientation (Figure 22.16). The process of polarization, however, causes the vibration direction to be restricted. Instead of vibrating in just any direction, polarized light will be vibrating only in one plane (Figure 22.17).

When light strikes a horizontal *reflecting* surface, it becomes partially polarized with the major direction of vibration being in the horizontal plane (Figure 22.18).

If light strikes the surface of a *refracting* material such as water or glass, most of the light will be refracted. It strikes the surface of the water and goes on into the water. The rest of the light will be reflected. There is an angle of incidence of the light striking a surface where not just some but all of the reflected light will be polarized. This angle is called *Brewster's angle* (Figure 22.19). See Box 22.3 for more on Brewster's angle.

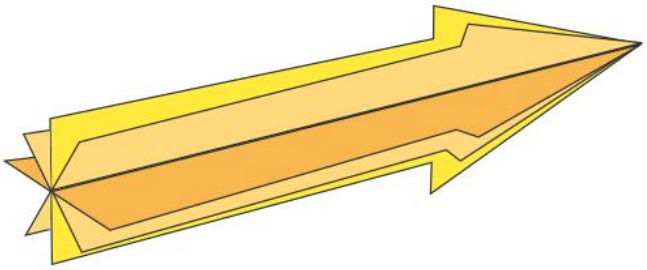


Figure 22.16 Light waves are not restricted to one direction of vibration. Light from a single source can vibrate in the vertical plane, in the horizontal plane, and in any plane in between simultaneously.

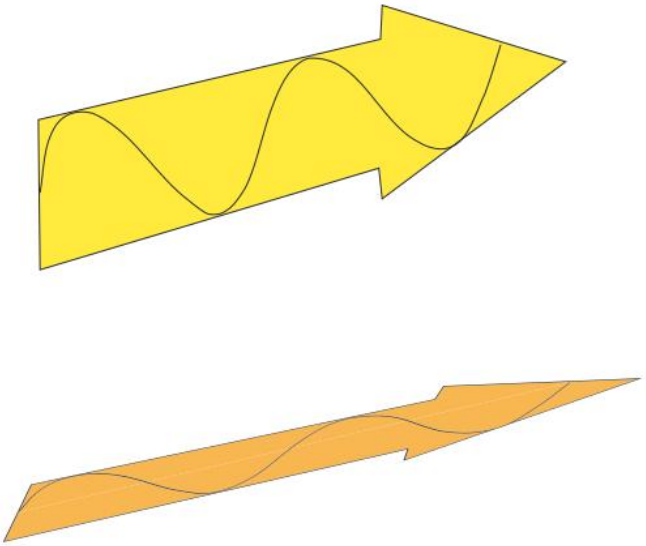


Figure 22.17 Polarized light vibrates in only one plane. The light at the top is vibrating vertically; the light at the bottom is vibrating horizontally. Polarized reflected light from water, sand, or snow is horizontally vibrating light.

To reduce the intensity of reflective glare more than that of surrounding objects, for prescription lenses, a thin polarizing sheet is mounted between hard resin or polycarbonate material. Alternately, it can be mounted on one layer of cellulose acetate butyrate material and molded directly into a plastic lens during the lens casting process.[35] Although reflected glare is not eliminated, it is much reduced in comparison with other objects in the visual field.

Because the polarizing element in the lens must be oriented to extinguish horizontally vibrating light, the lens blank may not be rotated (Figure 22.20). This necessitates custom grinding the rear surface of the lens so that both the direction of polarization and the cylinder axis are correct. In other words, nonspherical lenses must be individually surfaced, including single-vision lenses.

If an ideal polarizing filter is oriented properly and all incoming light is horizontally polarized, then all of the light would be extinguished. However, if the filter is tilted, then some light will get through. When the filter is 90 degrees away from where it should be, all of the horizontally polarized light will come through the filter. The amount of light that comes through depends upon the orientation of the polarizing filter. This amount is predictable and may be found using Malus' law. (For more on Malus' law, see Box 22.4.) If the polarizing lens is not oriented along the 180-degree meridian, not all horizontally polarized light will be absorbed. And if a person is wearing a polarizing filter and tilts his head to one side, the filter will not absorb as much of the horizontally polarized light. The more the head is tilted, the less horizontally polarized light is absorbed.

When Should Polarizing Lenses Be Used?

Polarizing lenses offer advantages in a number of different situations and can be recommended for the following reasons:

1. *To decrease driving fatigue and increase driving safety*—Because much of the light reflected from large pavement areas is polarized, those who do a lot of daytime driving will benefit from polarizing lenses. There is also polarized light that reflects off the inside of the windshield from the dashboard or from objects on the dashboard. This is an intensely distracting glare that will be almost totally eliminated with polarizing sunglasses.
2. *For fishing and for boating on the water*—Reflected light from the surface of water makes it hard to see below the surface. Wearing polarizing lenses not only removes the discomfort of reflected glare, but it also makes it easier to see below the surface.
3. *For more visual comfort at the beach*—Sand and water are both sources of polarized glare. Polarizing lenses are especially helpful here.
4. *So that colors are not bleached out*—Reflected polarized light produces a veiling glare. This veiling glare causes colors to appear less vivid. When glare disappears, colors return.
5. *So that bright, snowy days are not as blinding*—Snow is highly reflective. It is also polarizing. Those who are out working or driving in the snow will benefit from using polarizing lenses. (Note: Polarizing lenses may not be as advantageous for skiers as one might think. Skiers' heads tilt far to the left and right when skiers turn and lean. This makes the polarizing filter less effective when the frame front is no longer oriented parallel to the ground and causes changes in brightness.)
6. *To block UV radiation*—Virtually all prescription polarizing lenses, both glass and plastic, are made to block UV radiation. This is not a function of the polarizing filter but rather foresight on the part of the manufacturers. UV filtering is a big advantage, since the same surfaces that normally reflect light in a polarized manner also reflect a high percentage of UV light.
7. *Polarizing lenses are good sunglasses*—Polarizing lenses should be considered for ordinary sun lens wear.

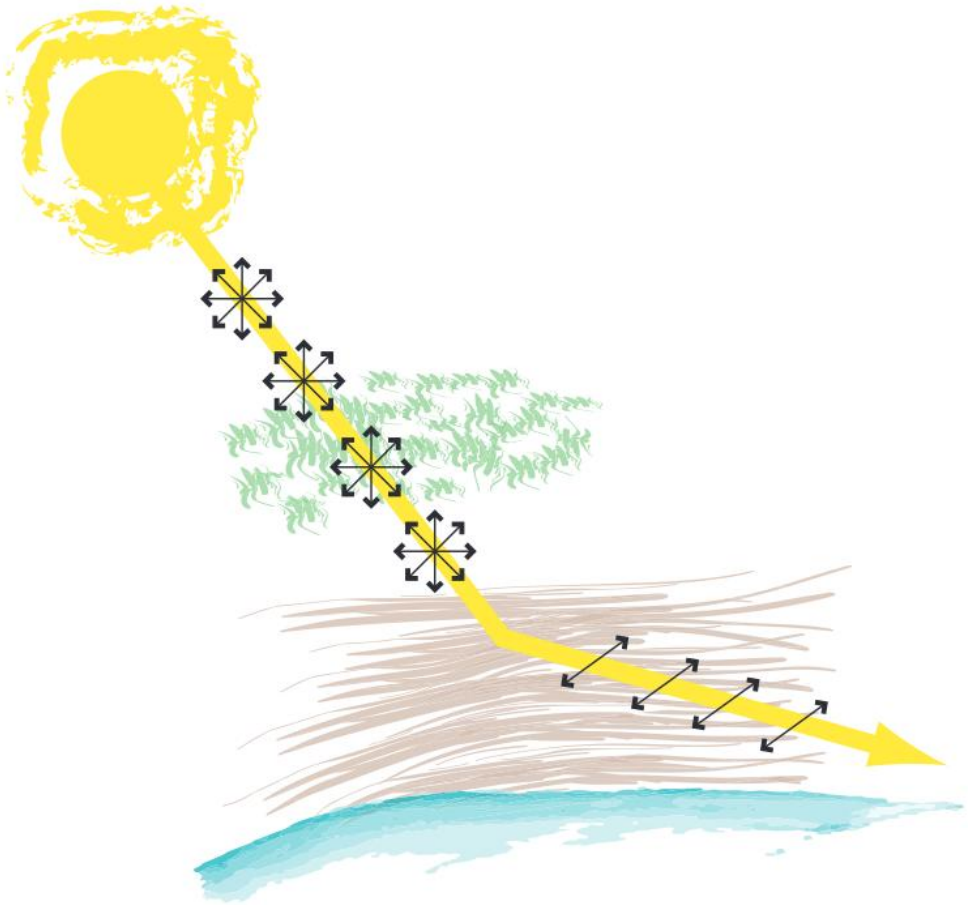


Figure 22.18 When light strikes a horizontal reflecting surface such as water or sand, it becomes partially polarized with the major direction of vibration being in the horizontal plane.

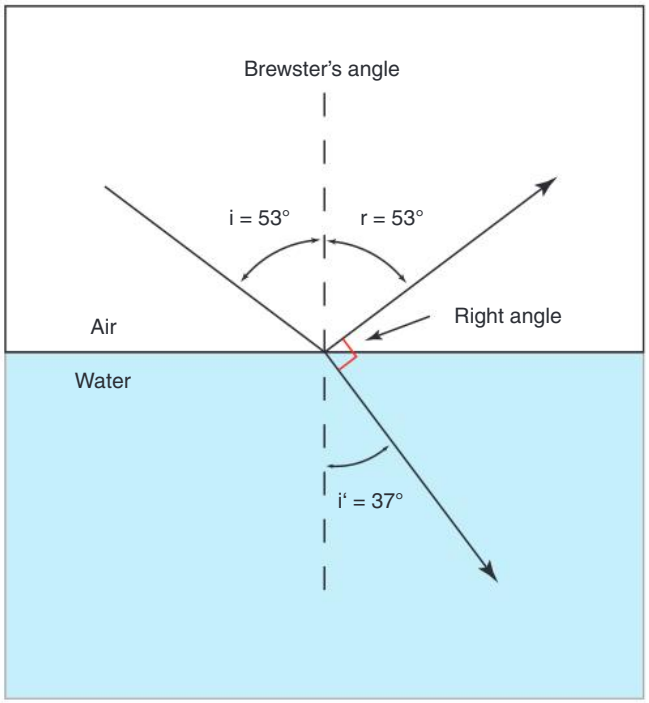


Figure 22.19 Brewster's angle is the angle where complete polarization of reflected light occurs. At Brewster's angle, the reflected and refracted rays are 90 degrees away from one another.

There are many cases of polarizing glare that occur routinely during outdoor activities. A surprising number of individuals would benefit.

Polarizing lenses are made in most lens styles—not just in single-vision lenses, but in bifocals, trifocals, and progressive addition lenses as well. They are available in most all lens materials—both plastic and glass. Colors and tints are available, including in mirrors and flash mirrors. Polarizing lenses may also be AR coated.

Precautions With Polarizing Lenses

There are some instances in which polarizing lenses create unique situations. Here are a few:

1. Since windshields are tempered, the tempering process induces intentional stress into the material. This stress may be visible through polarizing lenses in much the same way the stress is visible through the crossed polarizing filters of a colmascope (polariscope). A colmascope is used to check for impact resistance of glass lenses (see Chapter 23).
2. Some skiers believe polarizing lenses make snow conditions harder to judge. In addition, as the skier tilts from side to side, the polarizing lens tilts. The percentage of horizontally polarized light reflected from the surface of the snow and absorbed by the polarized lenses will vary depending upon the angle of tilt. This will cause an ongoing change in the intensity of the reflected light.
3. Some golfers find that polarized lenses make judging the condition of the course more difficult since the smooth grass surface causes a certain amount of helpful polarization of reflected light.

BOX 22.3 Brewster's Angle

When light strikes a refracting surface, most light is refracted into the media, and some is reflected. The reflected light is partially polarized until it reaches a certain angle when it is completely (linearly) polarized. This angle is where the reflected light and the refracted light are at right angles to one another and is called the *angle of polarization* or *Brewster's angle*.

The angle of polarization happens when the reflected light is at right angles to the refracted light (see Figure 22.19). The angle of polarization is measured as the angle of incidence (i) of light striking the surface when the right angle condition for reflection and refraction is met. Figuring out what this angle of incidence will be is done using Snell's law. Snell's law says that the index of the first media (n) times the sine of the angle of incidence (i) is equal to the index of the second media (n') times the sine of the angle of refraction (i). This is written as:

$$n \sin i = n' \sin i'$$

We know that, for Brewster's angle, the reflected light and the refracted light are at right angles to one another, which means that

$$r + i' + 90 = 180$$

where r is the angle of reflection and i' is the angle of refraction.

This equation reduces down to

$$i' = 90 - r$$

We also know that, for reflected light, the angle of incidence and the angle of reflection are always the same. In other words,

$$i = r$$

This means that we can substitute i for r so that

$$i' = 90 - r$$

becomes

$$i' = 90 - i$$

Going back to Snell's law and substituting $(90 - i)$ for i' results in

$$n \sin i = n' \sin (90 - i)$$

From trigonometry, we know that

$$\sin (90 - i) = \cos i$$

so that Snell's law can now be written as

$$n \sin i = n' \cos i'$$

then changed algebraically to

$$\frac{\sin i}{\cos i'} = \frac{n'}{n}$$

Using mathematical principles, we know that if

$$\sin = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

and

$$\cos = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

then

$$\frac{\sin}{\cos} = \frac{\dfrac{\text{Opposite}}{\text{Hypotenuse}}}{\dfrac{\text{Adjacent}}{\text{Hypotenuse}}} = \frac{\text{Opposite}}{\text{Adjacent}} = \tan$$

so now

$$\tan i = \frac{n'}{n}$$

If the first media is air, then $n = 1$ and the equation becomes:

$$\tan i = \frac{n'}{1}$$
$$\tan i = n'$$

In this equation, i is Brewster's angle.

Usually, we already know the refractive index of the media and want to know Brewster's angle (i). We can find i by using the inverse tangent.

$$i = \tan^{-1} n'$$

Example

What is the angle at which any reflected light will be completely polarized when light strikes water?

Solution

Using the formula for Brewster's angle allows us to find the angle of complete polarization. Knowing that water has a refractive index of 1.33, we can find the angle of incidence that corresponds to Brewster's angle and produces complete polarization of all reflected light.

$$i = \tan^{-1} n'$$
$$= \tan^{-1} 1.33$$
$$= 53 \text{ degrees}$$

For water, Brewster's angle is 53 degrees. This is shown in the figure. Note that the angle of reflection and angle of refraction are at 90 degrees to one another. This always occurs for Brewster's angle.

4. The instrument panels in some vehicles use liquid crystal displays (LCDs) to display information. An LCD display is polarized. If the LCD is horizontally polarized, polarizing sunglasses will extinguish the display. To see how this works when wearing polarizing lenses, turn the display of an LCD display watch 90 degrees. The time display will disappear. Or when pumping gas while viewing the display on the gas pump, tilt your head sideways and see the numbers fade out.

   This can also be a problem with some heads-up automobile displays that reflect off the windshield so the driver does not need to look down to the instrument panel. Not all heads-up displays cause the reflected display to disappear. But if the display seen reflected from the windshield is horizontally polarized, the display will either disappear or be almost extinguished.
5. Pilots experience a number of adverse situations when wearing polarizing lenses, some of which can be dangerous.

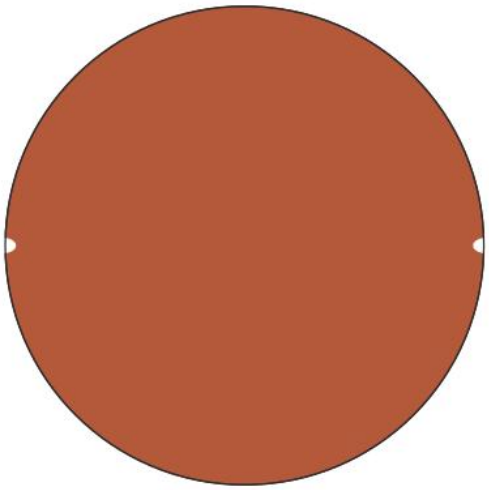


Figure 22.20 This finished, uncut polarizing lens has two notches cut out on the sides so that it is clear how the lens should be oriented to maintain the intended polarizing properties.

BOX 22.4 Malus' Law

A polarizing filter has an absorption axis and a transmission axis. If an ideal polarizing filter is oriented with its absorption axis along the 180-degree meridian, it will extinguish all horizontally polarized light. This means that the transmission axis of this same filter will be at 90 and will allow all vertically polarized light to pass through. When the filter is tilted somewhere between these two positions, only a certain percentage of horizontally polarized light comes through the filter.

Malus' law is a predictor of how much polarized light will be transmitted by an obliquely oriented polarizing filter. It is expressed by the equation

$$I_x = I_o \cos^2 \theta$$

I_X is the intensity of the light transmitted through the filter, I_O is the original intensity of the entering light, and θ is the angle of tilt with *reference to the transmission axis*. The equation for the traditional form of Malus' law is based on the transmission axis not the absorption axis. For polarizing ophthalmic lenses, the absorption axis is oriented at 180. The transmission axis is at 90.

Example

A polarizing filter used in a lens has its absorption axis oriented along the 180-degree meridian. We will assume that it is an ideal filter and will absorb all horizontally polarized light. The polarizing lens is being worn by a person who tilts his head 30 degrees. What percent of horizontally polarized light will now be allowed to pass through the tilted filter?

Solution

Assuming that we have 100% of incoming horizontally polarized light striking the filter, then the intensity of the irradiating (incoming) horizontally polarized light (I_O) is 1. Remember that Malus' law is based on the transmission axis. When the wearer tilts his head 30 degrees, the transmission axis of the lens is 60 degrees away from the horizontally polarized light. Using Malus' law

$$\begin{aligned} I_x &= I_o \cos^2 \theta \\ &= 1 \cos^2 60 \\ &= 0.25 \end{aligned}$$

Therefore, the intensity of the horizontally polarized light passing through the filter is 25%. So tilting the head while wearing polarizing lenses will allow 25% of polarized reflected light to pass through, making the tilted lens a less effective glare filter.

a. Polycarbonate windshields in many aircraft have stress patterns. These patterns become visible and may be distracting when wearing polarizing lenses.
b. Some airplane cockpits, like some car instrument panels, may have polarized numbers or images that can disappear when viewed through polarizing lenses.
c. Much of the light from an oncoming aircraft that makes it visible is reflected light from the metallic surfaces of the plane. Much of this reflected light is horizontally polarized. When this reflected light is eliminated by horizontally polarizing sunglasses, the oncoming aircraft may not be seen as soon as it would otherwise have been.

Two Methods for Demonstrating Polarizing Lenses

It is helpful to explain how polarizing lenses work to a prospective buyer, but it is much better to show them with a first-hand demonstration. Here are two methods that show how polarizing lenses affect light. (There are also commercially available demonstration units.)

It is possible to take two plano polarizing lenses and, by holding one before the other with their polarizing axes crossed at 90 degrees, eliminate all incoming visible light rays. What one polarizing lens does not extinguish, the other will. To demonstrate how polarizing lenses work with this method, hold one lens still, then rotate the other lens back and forth 90 degrees. Watch objects viewed through the lenses dim out completely, then brighten up as the lens is rotated back.

(Caution: When crossed sheets of polarizing material or lenses are not quite 90 degrees apart, only a small portion of the light is admitted. Herein lies a potentially dangerous problem. Some wearers may be inclined to use your demonstration system with one polarizing lens and one sheet polarizer or two pairs of polarizing glasses for viewing an eclipse of the sun. Unfortunately, Clark[36] reports that plastic sheet polarizers are inefficient polarizers of IR radiation—as are most spectacle lenses. Therefore, an inordinate amount of heat-producing IR reaches the retina and, especially when combined with UV or short wavelength blue light, would be damaging. Direct viewing of an eclipse, even with highly absorptive lenses, is *never* advisable.)

A second method for demonstrating how polarizing lenses work uses a pair of glasses with polarizing lenses and a glossy magazine.[37] Place the magazine on a flat surface with a light source in the background. With the glossy magazine between you and the light source, the magazine will show a reflecting glare. Move around until the glare is maximal. Now turn the glasses 90 degrees so that the lenses are vertically aligned instead of horizontally as when worn. View the magazine through one of the lenses. Now, slowly rotate the glasses until they are horizontal again. As the glasses are rotated, the glare on the magazine will decrease.

GLARE CONTROL LENSES

Polarizing lenses correct reflective glare. There are other types of glare that polarizing lenses alone cannot eliminate, however. Glare problems are corrected by addressing the type of glare experienced. For our purposes, we will divide glare into two types: (1) discomfort glare and (2) disability glare. These two types of glare are similar in cause but different in their effect upon vision. *Discomfort glare* is a "glare which produces discomfort but does not necessarily interfere with visual performance or ability."[38] *Disability glare* "reduces visual performances and visibility [and] may be accompanied by discomfort."[38]

Discomfort Glare

Discomfort glare may occur when the eyes try to cope with high and low light intensities in a relatively small viewing area. The eyes have difficulty adjusting to both lighting situations simultaneously.

Discomfort glare is best corrected by a change in environmental factors. Individuals working at a computer screen placed in front of a bright window experience discomfort glare from the surrounding area. The problem is corrected by repositioning the computer or shading the window. Discomfort glare is also experienced when viewing a television in a dark room. When an individual must look back and forth between vastly different illuminations, discomfort is experienced. Put another way, stray light that reduces visual comfort but does not interfere with resolution is called discomfort glare.[39]

Disability Glare

Disability glare occurs when stray light interferes with contrast, making it difficult to resolve an image. Stray light washes out the image on the retina in the same manner that strong overhead lighting degrades the image on a projector screen.

If the stray light causing glare were made up of just polarized light, it could be eliminated using a polarizing filter. If the stray light causing problems were to originate from a light source of only one color, a selectively absorptive lens capable of filtering out only that one color would be able to screen out the offending light, restoring the quality of the image.

Factors That Cause Disability Glare

There are many situations that cause disability glare. For example, dazzlingly bright oncoming headlights can obscure a dark road, making it nearly impossible to see someone in dark clothing walking along the side of the road. In addition, there are factors that can cause or increase disability glare. One such factor is the presence of a cataract. If the crystalline lens begins to cloud and fog up like a dirty windshield, disability glare can increase. Oncoming headlights at night are bad enough when viewing the scene through normal eyes. When those same intense headlights are passing through a cloudy, light-scattering cataract, the effect is considerably magnified.

Another cause of increased glare may be related to the absorption of UV light by the crystalline lens. As the crystalline lens of the eye absorbs UV and short wavelength visible light between the range of 310 and 410 nm, it fluoresces, giving off light with a wavelength near 530 nm.[40] Contact lens practitioners will see the pupil giving off a greenish-yellow cast when viewing the eye with a UV light source. This is really fluorescence of the crystalline lens as seen through the pupil.

Additional Protection From Glare Using Side Shields

The person who is especially sensitive to glare, such as someone with corneal scarring, may benefit from the use of side shields. These shields may be tinted and attached to prescription spectacles.

A wraparound frame is like a frame with built-in side shields. Wraparound frames are available in regular sunglasses or in specialty filters, such as NoIRs or Solar Shields. Many of these specialty filters are made to be worn by themselves or over conventional eyeglasses.

Using Absorptive Filters That Block Short Wavelengths

The effects of UV radiation on the retina are known and have been discussed in an earlier section of the chapter. In addition to UV light, there are some damaging effects of blue light reported.[41,42] There is enough short wavelength light generated by ophthalmic instruments to cause ocular damage with sufficient exposure.[43] However, there are normally filters used in these instruments to prevent such damage.

Another rationale for using a lens that blocks short wavelength light is to try to increase contrast. When a blue object is viewed through a lens that filters blue, the object does not disappear but looks darker. A darker object against the same background will have a higher border contrast. For this reason, lenses that filter out short wavelength light are said to increase contrast.

Lenses Made to Block Short Wavelengths and Control Glare

Several lenses made their appearance in the 1980s that have been used in an attempt to control glare. Some of these lenses have been used heavily by low-vision practitioners and by those who see a large proportion of older wearers.

Glare Control Corning Protective Filter Lenses

Corning developed a series of photochromic lenses referred to as Glare Control CPF lenses. This line of lenses has since been acquired by Winchester Optical.[44] They are specialty photochromic glass lenses made using a unique manufacturing process.

There is a series of these lenses, each with a coded name, such as the CPF 527. The letters "CPF" stand for "Corning protective filter." The number indicates the wavelength below which light is absorbed. (For the CPF 527 lens, all UV and visible light up to 527 nm is absorbed by the lens.)

CPF lenses are described and compared in Table 22.3. Some of their transmission curves in lightened and darkened states are shown in Figure 22.21.

None of these Glare Control lenses are to be worn for night driving, and some are also contraindicated for daytime driving.

Glare Control Dyes

There are glare control "colors" available in lens dyes. This is a less expensive option, whereby clear plastic lenses may be tinted to the desired absorptive characteristics. These are not photochromic lenses and so will only have one transmission curve instead of both light and dark transmission curves. This is the option of choice for those who do not need the variable transmission of the photochromic CPF glass lens. To protect from glare as anticipated, the dyed-in tint should not just match an equivalent expected lens color, but the absorptive properties of the dyed lens should also fulfill the needed spectral transmission requirements.

Nonprescription Options for Controlling Glare

Well-known nonprescription filters for controlling glare are available from companies such as NoIR Medical Technologies.[45] These are wraparound glasses that come in sizes allowing them to be used alone or on top of prescription eyewear.

Disadvantages of Glare Control–Type Lenses

There are certain disadvantages associated with lenses that block the short wavelength visible spectrum. One of the disadvantages of these lenses is their possible effect on color vision. The amount and type of color confusion will vary depending upon the lens. The more of a certain sector of the visible spectrum that is absorbed by the lens, the greater may be the effect on color vision.

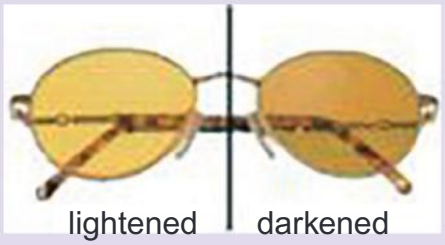
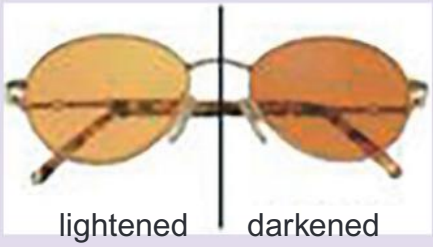
For individuals with normal color vision, there may be no color confusion induced for lenses that absorb moderately in the blue end of the spectrum.

Color discrimination will be more noticeably affected for individuals who already have a color deficiency. Scores on standardized color testing decrease notably for people with color vision deficiency.

The expectation with glare control lenses is that visual performance will improve. However, improvements in visual performance by individuals who would be considered candidates for these types of lenses is not a given. In fact, there may be no statistically significant difference in visual acuity or contrast sensitivity with the glare control–type lens compared with a neutral density filter of the same transmission.[46,47] Reported improvement in vision is more of a subjective assessment on the part of the wearer. Therefore, decisions on which lenses to

TABLE 22.3 The Family of GlareControl™ Lenses

GlareControl™ lenses meet the ANSI Z80.3 requirements for special purpose ultraviolet (UV) absorption. UVA (315–380 nm); UVB (290–315 nm). Reported UV numbers are measured in the darkened state.

Original CPF Series	**CPF® 450™** Lightened 67% Darkened 19% UVA blockage 99% UBV blockage 100%		A lightly colored lens comfortably enhances contrast and helps control glare indoors. For reading, watching television, and coping with fluorescent lights in offices and supermarkets. Frequently chosen for • Optic atrophy • Albinism • Pseudophakia
	CPF® 511™ Lightened 44% Darkened 14% UVA blockage 100% UBV blockage 100%		Medium-range filter provides moderate blue light filtering while permitting longer wavelengths of lower energy light to pass through. Especially helpful for individuals with • Macular degegeneration • Developing cataracts • Glaucoma • Aphakia • Pseudophakia • Optic atrophy
	CPF® 527™ Lightened 32% Darkened 11% UVA blockage 100% UBV blockage 100%		Orange-amber lens darkens to brown in sunlight, giving individuals better visual function and reduced glare. Frequently chosen by people with • Diabetic retinopathy • Photophobia • Retinitis pigmentosa
	CPF® 550™ Lightened 21% Darkened 5% UVA blockage 100% UBV blockage 100%		The original GlareControl lens relieves the stress of intense sensitivity to light and poor dark adaptation. Lens color varies from orange-red when lightened to brown when darkened. Proven helpful for individuals with • Retinitis pigmentosa • Albinism
X-Series	**CPF® 450X™** Lightened 68% Darkened 20% UVA blockage 99% UBV blockage 100%		A lightly colored comfort lens provides a more natural color scene while enhancing contrast and controlling glare, particularly indoor light. Helps reduce discomfort over a wide range of light levels, including fluorescent lighting and glare from television sets. Available in progressives. Frequently chosen for people with • Beginning to moderate light sensitivity • Early onset macular degeneration • Optic atrophy and albinism • Pseudophakia
	CPF® 511X™ 33% 15% 99% 100%		Medium-range filter provides moderate blue light filtering with improved contrast and a stylish, attractive appearance. Available in progressives. Especially helpful for individuals with • Age-related macular degeneration • Developing cataracts • Glaucoma • Aphakia and pseudophakia
	CPF® 527X™ Lightened 33% Darkened 15% UVA blockage 99% UBV blockage 100%		Third in a series of X-lenses developed in the late 1990s based on input from low vision practitioners. Provides a more natural color scene and greater contrast while giving individuals better visual function and reduced glare. Available in progressives. Prescribed for people with • Diabetic retinopathy • Retinitis pigmentosa • Macular degeneration • Cataracts

From Winchester Optical, Elmira, NY. https://www.winoptical.com/Uploads/page-files/documents/module/Glare-Control/Glare-Control-patient-brochure.pdf. Accessed 02/21/2022. Used with permission.

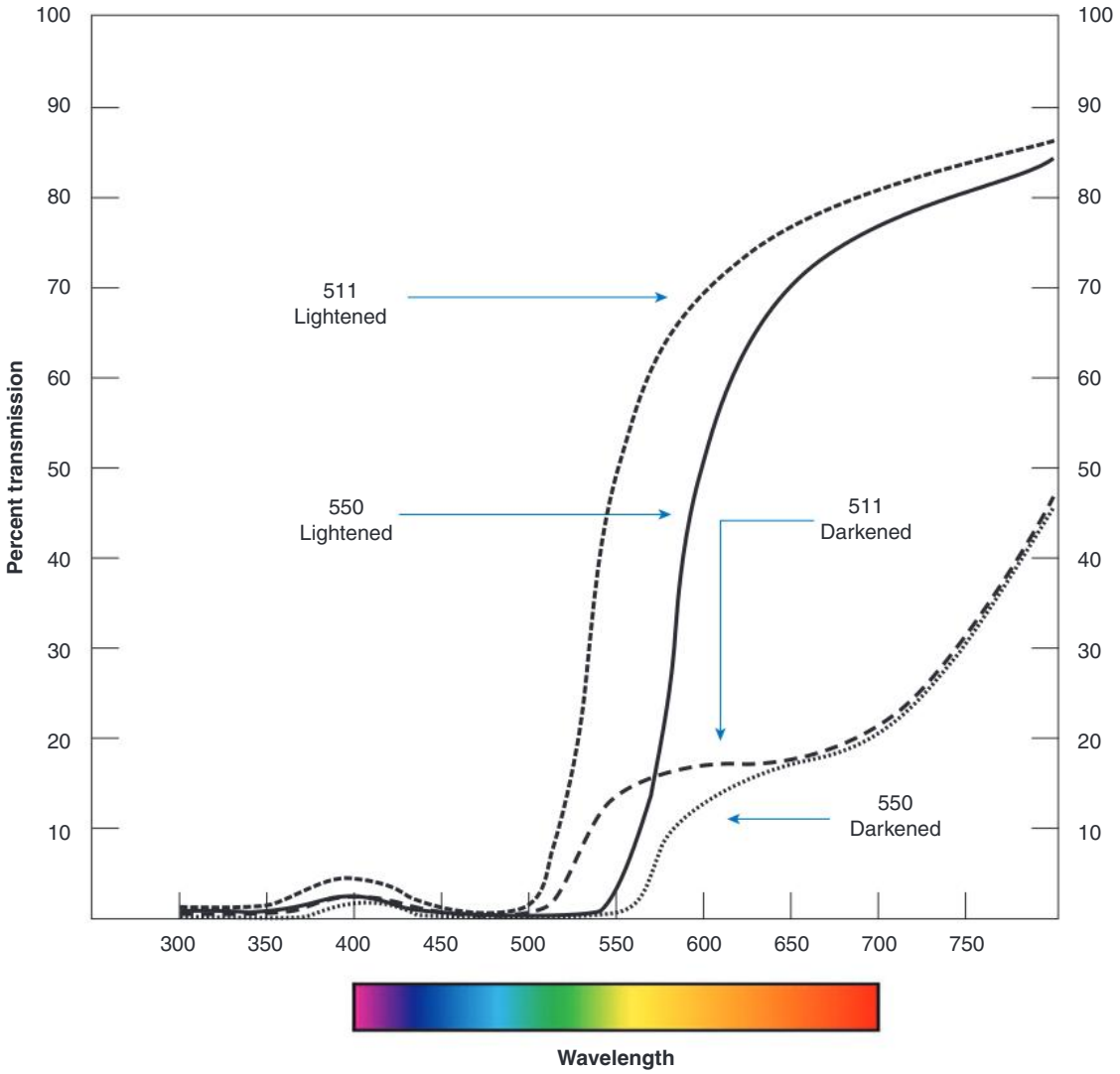


Figure 22.21 Transmission curves for two of the standard series CPF Glare Control lenses. Note that CPF lenses block wavelengths below the identifying number for the lens (i.e., for the 550 lens, no significant amount of light with a wavelength shorter than 550 nm is transmitted through the lens). Spectral transmission curves for the CPF 527 lens (not shown in the figure) fall between the transmission curves for the 511 and 550 lenses. (From *Corning Glare Control Lens Manual, OPM 190*, Corning, NY: Corning Inc.; 1991.)

use are usually made by the individual subjectively comparing two or more appropriate lens types.

Clinically, glare control–type lenses continue to enjoy popularity, especially in practices specializing in vision rehabilitation. Although not everyone with glare problems or degenerative eye disorders may find the lenses beneficial, those who do wear them report a subjective improvement in vision and satisfaction.

SPECIALTY ABSORPTIVE LENSES

Specialty Absorptive Lenses Use Specific Selective Absorption

All absorptive lenses use selective absorption, even if it is to selectively absorb all wavelengths evenly across the visible spectrum as with gray lenses. Brown lenses selectively absorb short wavelength light the most, gradually allowing an increase in transmission toward the longer wavelengths in a slope-like fashion. Yellow lenses allow almost none of the shorter blue wavelengths of light through the lens up until a wavelength of approximately 475 nm. Then, transmission increases abruptly, allowing nearly 90% transmission through the lens in the mid- to long wavelength regions of the spectrum.

Types of Color Deficiency

There are two main types of photoreceptors—rods and cones. The rods operate at very low levels of light and are used for night vision. They are located in the peripheral retina and not in the most sensitive foveal area of the retina used in central vision. Rods do not perceive color.

Cones operate at higher light levels and are responsible for color vision. Color vision occurs because there are three types of cones. Each of these cone types is sensitive to three different wavelength areas. There are the S-cones with short wavelength sensitivity, M-cones with middle wavelength sensitivity, and L-cones with long wavelength sensitivity. S-cones perceive blue light, M-cones perceive green light, and L-cones perceive red light (Figure 22.22). It can be seen in the figure that there are overlaps in these sensitivity curves. More than one cone type may be activated by the same wavelength. An individual with normal color vision with all three cone types functioning normally is called a *trichromat*. All three main colors are perceived normally.

A person who lacks one cone type or has a much-reduced sensitivity for that retinal cone is called a *dichromat*. They are only seeing color with two of the three cone types. When only one cone type is functional, a person with this disorder is called a *monochromat*. Both di- and monochromats are usually classified as being color blind, even though dichromats do have some color vision. If the dysfunctional cone is the S-cone, the disorder is called *tritanopia*; if the M-cone is dysfunctional, the disorder is called *deuteranopia*; and if the L-cone is dysfunctional, the disorder is called *protanopia*. A person lacking in cones that are sensitive to longer wavelength (red) light cannot differentiate red from green. Likewise a person lacking cones sensitive to the green area of the visible spectrum will have a similar red-green color discrimination problem. A person lacking cones sensitive to blue light cannot differentiate blue from yellow light, although this is rare.

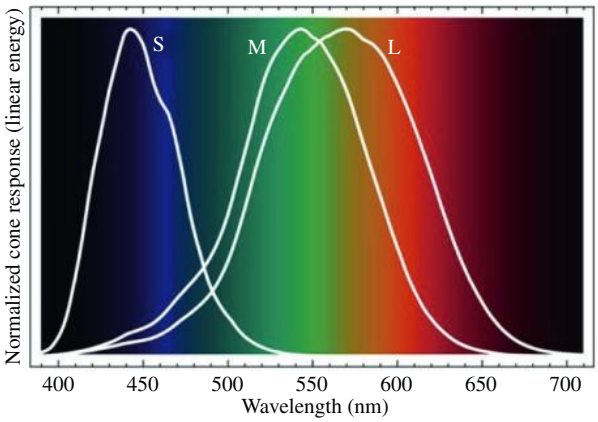


Figure 22.22 The sensitivity peaks for S-, M-, and L-cones will vary by individual and may fall between approximately 564–580 nm, 534–545 nm, and 420–440 nm. (BenRG, Cone Cell. https://en.wikipedia.org/wiki/Cone_cell#:~:text=S%20Cones%20are%20most%20sensitive,therefore%20called%20ultraviolet'%20light. Wikipedia, public domain figure. Accessed 02/22/2022.)

A person with a color discrimination problem who has all three cone types functioning but with one or more cone types tuned to an atypical peak sensitivity wavelength, is called an *anomalous trichromat*. An anomalous trichromat may have a *protanomaly*, a *deuteranomaly*, or a *tritanomaly*, depending upon whether red, green, or blue cones are affected. Most of the time, the red or green cones are affected. The red/green problem is usually caused because the peak of the red sensitivity curve is shifted toward the peak of the green curve (protanomaly), or the green curve peak is shifted toward the peak of the red curve (deuteranomaly). Because the red and green curves have too much overlap, that person loses some or much of their red-green color discrimination (Figure 22.23).

Colored Filters for Color Deficiency[48]

Using a filter that selectively absorbs certain colors but not others will change the intensity of those colors, making it possible for a person with color vision deficiency to use light intensity cues to tell one color from another that may not have been previously distinguishable. These intensity differences are helpful when intensities can be compared with and without the specialized filter.

A red filter will make a green object look dimmer than a red object. Selective filters for this purpose have been attempted with colored contact lenses such as the red X-chrome lens worn on one eye or the

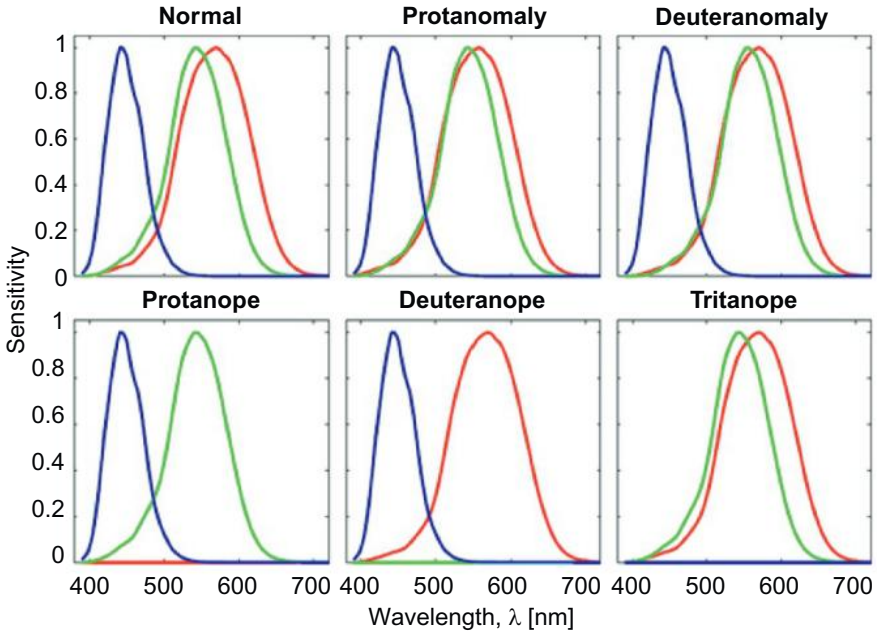


Figure 22.23 The three lower diagrams represent individuals with only two functioning cone types referred to as dichromats. The top left diagram for individuals with normal color vision shows that even though the red and green-sensitive cones have their peaks placed closely together, those peaks are still separated enough to allow normal red-green color discrimination. For the person with protanomaly, the red curve is shifted too far to the left. For the person with a deuteranomaly, the green curve is shifted too far to the right. In both cases there will be red/green color confusion. (Reprinted from Shrestha, R. Simulating Colour Vision Deficiency from a Spectral Image, Universal Design 2016: Learning from the Past, Designing for the Future, H. Petrie et al. (Eds.), Copyright © 2016 with permission from IOS Press. The publication is available at IOS Press through https://doi.org/10.3233/978-1-61499-684-2-392.)

ChromaGen contact lens available in different colors, depending upon defect type. (These filters are also available in the form of spectacle lenses.) Filter contact lenses are placed on one eye only so that when closing first one eye, then the other, intensity variations are comparable. Some spectacle lens color filters are placed in only one sector of a spectacle lens so that a comparison of how the object appears can be made by moving the head. The object can be viewed first without, then with the filter.

Certain filters cause other colors to appear more vivid to people with color vision deficiency because of the manner in which perceived colors shift in appearance when viewed through the filter.

Negative Effects of Colored Filter Lenses for Color Deficiency

Colored filters worn over both eyes for the purpose of helping certain colors to be better distinguished by people with color deficiency can cause problems. This is because colors that were distinguishable before may now be confused when viewed through the filter.

Even a colored filter, such as the X-Chrom contact lens, worn over one eye is not without a down side. One problem is that objects may appear to glisten. (This is called *binocular luster*.) A second problem may occur when there is a difference in intensity between the two eyes. Moving objects may appear to be wrongly located as to how far away they appear (called the *Pulfrich phenomenon*). Sheedy points out that "The red contact lens may drastically improve performance on pseudoisochromic plates (used to test color vision), but the improvement is spurious and does not properly represent the small improvement in real world performance."[49]

Notch Filters for Color Deficiency

A system that is designed to help some red/green anomalous trichromats recognizes that too much overlap between the red and green sensitivity curves will cause color confusion. In an attempt to reduce this confusion, a notch filter lens is used. A *notch filter* is one that selectively filters by cutting a notch in the visible spectrum at a specific location. In the instance of red/green anomalies, that notch is sliced out between the peaks of the red/green sensitivity curves somewhere near 580 and 590 nm. This is meant to eliminate the areas of greatest overlap and greatest confusion.

There is also a second notch in the blue/green spectral area near the 480- to 490- nm region. This is near the area where blue and green spectral sensitivity curves show the most amount of overlap. The second notch at this location is intended to enhance color perception (Figure 22.24).

The EnChroma lens was a pioneer in using this notch filter principle. EnChroma lenses are available in a variety of styles designed for protanomalous and deuteranomalous color deficiency; some are for indoor use, and others are designed as outdoor sun wear. Because of the continuum of deficient color vision severity, notch lenses cannot be expected to please or help every individual with color deficiency.

Sports and Sunwear Lenses With Notch Filters

When notch filters are used with the notches falling in the areas of highest overlap between blue and green and between green and red spectral sensitivity curves, colors change in perceived intensity even for individuals with normal color vision. Some individuals notice a subjectively larger change than others.

This effect is used in conjunction with selective absorption or transmission of other wavelength areas to create absorptive filters intended for use with specific sports or activities. For example, one of the Oakley Prizm™ specialty sports lenses, the Prizm™ Field lens, is intended for use in baseball or in other field sports. Oakley reports that with this lens they are aiming for two key features:

1. "Accentuates blues and keeps whites bright so you can see the ball well against the sky.
2. "Increases saturation of grass and dirt for contrast with the ball. Increase in red also allows you to read the pitch better by enhancing the red stitching on the ball."[50]

This lens is intended for daylight use. A different lens with greater transmission and less of a sunglass lens is recommended for low light use.

Lens manufacturers produce a large number of specialized sun and sports lenses that use a combination of notches and wavelength-specific transmissions.

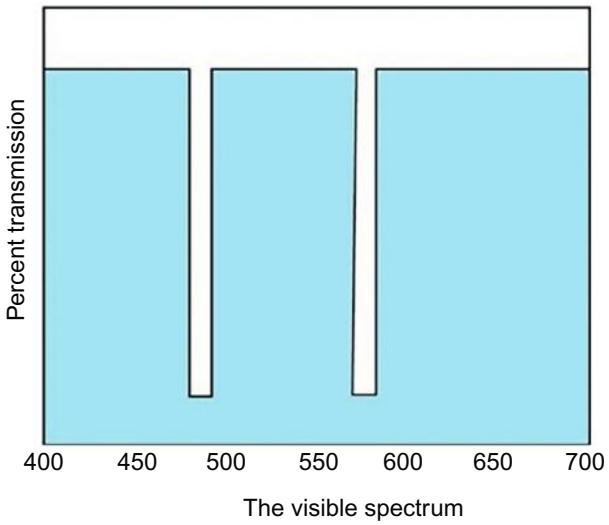


Figure 22.24 Here is a schematic example of a notch filter with two notches. There is still some transmission coming through since the notches do not extend all the way down to zero transmission. When notches are placed at the locations of maximum overlap between blue and green transmission curves and green and red curves, the intent is a reduction in color confusion and an increased enhancement between colors.

Shutter Glasses for Amblyopia

Electronic shutter glasses have been used for amblyopia therapy, forcing the amblyopic or "lazy eye" to become actively involved in vision. This may be done by switching the lens in front of the eye with better vision from "viewing" to "off" at regular intervals. In a pilot randomize clinical trial, results found that therapy with liquid crystal glasses was not inferior to adhesive patching for children 3 to 8 years of age with moderate amblyopia.[50]

Although FDA approved, these glasses have not yet found widespread usage in the United States. This may not change because of the success of video gaming programs aimed at requiring use of both eyes for optimal play.

Glass Blower's Lenses

Glass blowers prefer an absorptive lens that filters out the yellow band of the spectrum so that they may more clearly see what is happening to the color of the heated glass without it being masked by the yellow flame. This function is fulfilled with a glass *didymium filter* lens. Didymium lenses are dichroic, meaning the lens will appear rose colored in natural and incandescent lighting but aqua under fluorescent lighting. Didymium lenses used in glass blowing *are not welding*

glasses, even though there are some welding glasses that contain didymium. Didymium are not the only type of lenses used by glass blowers but are used by a substantial number of them.

X-Ray Lenses

Lenses used for x-ray protection are normally made from a 1.80 index lead or lead equivalent glass material. This particular glass is softer than regular glass and is prone to scratching. (Note: Just because a lens may have an index of refraction of 1.80 does not mean that it protects against x-rays.) People needing x-ray protective glasses often obtain their eyewear through distributors of equipment for radiation protection. They are available in single-vision, laminated bifocal, and laminated progressive lenses. Wraparound frames are advisable as some increase in protection is gained laterally because of the frame design.

ABSORPTIVE LENS CALCULATIONS

How Index of Refraction Affects the Transmission of a Spectacle Lens (the Fresnel Equation)

The amount of light that is reflected when light goes from one media to another is determined using the Fresnel equation. The Fresnel equation is

$$I_R = \left[\frac{n' - n}{n' + n}\right] \times I$$

where n' is the index of refraction of the second media, n is the index of refraction of the first media, I is the amount of incident light, and I_R is the amount of incident light that is reflected.

Example 22.2

What percentage of light can we expect an absolutely clear CR-39 plastic lens to transmit if it has an index of refraction of 1.498?

Solution

Using the Fresnel equation, we substitute the index of air, which is 1, for n, and the index of CR-39 plastic for n'. The amount of incident light, I, is 100% or 1. Therefore, the amount of incident light that is reflected from the front surface equals:

$$\begin{aligned} I_{R(Front)} &= \left[\frac{n' - n}{n' + n}\right]^2 \times I \\ &= \left[\frac{1.498 - 1}{1.498 + 1}\right]^2 \times 1 \\ &= \left[\frac{0.498}{2.498}\right]^2 \times 1 \\ &= [0.1994]^2 \times 1 \\ &= 0.0398 \end{aligned}$$

Reflected light expressed as a percentage is

$$R_F = 100(I_R)$$

Therefore, reflected light from the front surface of the lens will be

$$R_F = 100(0.0398) = 3.98\%$$

To determine how much light is reflected from the second surface, we run through the equation again. This time the value of the incident light is not 100% or 1. Instead it is

$$I = 1 - 0.0398 = 0.9602$$

Therefore,

$$\begin{aligned} I_{R(Back)} &= \left[\frac{n' - n}{n' + n}\right]^2 \times 0.9602 \\ &= \left[\frac{1 - 1.498}{1 + 1.498}\right]^2 \times 0.9602 \\ &= \left[\frac{-0.498}{2.498}\right]^2 \times 0.9602 \\ &= [-0.1994]^2 \times 0.9602 \\ &= 0.0398 \times 0.9602 \\ &= 0.0382 \end{aligned}$$

Expressed as a percent, the light reflected from the back surface is

$$R_B = 100(0.0382) = 3.82\%$$

Because of reflection from the front surface, only 96.02% of the light ever reaches the second surface of the lens. At the second surface, 3.82% of the light is reflected. This means that total light transmitted through the lens will be $96.02\% - 3.82\% = 92.2\%$.

Why High-Index Lenses Work Best With an Antireflection Coating

High-index lenses work much more to the wearer's satisfaction if they are AR coated. The reason can be seen when figuring the percentage of light transmitted by a high-index lens.

The uncoated higher-index plastic lens in the example transmits only 88% of the incident light in its clear state. This is the same

Example 22.3

How much light is transmitted by an absolutely clear, uncoated plastic lens having an index of refraction of 1.66?

Solution

Using the Fresnel equation, the index of air remains as 1, and 1.66 is used for n'. Therefore,

$$\begin{aligned} I_{R(Front)} &= \left[\frac{n' - n}{n' + n}\right] \times I \\ &= \left[\frac{1.66 - 1}{1.66 + 1}\right]^2 \times 1 \\ &= \left[\frac{0.66}{2.66}\right]^2 \times 1 \\ &= [0.248]^2 \times 1 \\ &= 0.0616 \end{aligned}$$

and

$$R_F = 100(0.0616) = 6.16\%$$

This means we have already lost more than 6% of the light to reflection from the first surface. Next, we find the amount of light that is incident on the second surface.

$$I = 1 - 0.0616 = 0.9384$$

Therefore,

$$
\begin{aligned}
I_{R(Back)} &= \left[\frac{n' - n}{n' + n}\right]^2 \times 0.9384 \\
&= \left[\frac{1 - 1.66}{1 + 1.66}\right]^2 \times 0.9384 \\
&= \left[\frac{-0.66}{2.66}\right]^2 \times 0.9384 \\
&= [0.248]^2 \times 0.9384 \\
&= 0.0616 \times 0.9384 \\
&= 0.0578
\end{aligned}
$$

This means that the percent of light reflected from the back surface is

$$R_B = 100(0.0578) = 5.78\%$$

If 93.84% of the light strikes the second surface and 5.78% is reflected from that surface, then the total light transmitted through the lens will be 93.84% − 5.78% = 88.06%.

transmission as a lightly tinted crown glass or CR-39 plastic lens. Fortunately, an AR coating will bring the lens back up to nearly 100% transmission. When these greater-than-normal lens reflections are eliminated with AR coating, the high-index lens becomes much more cosmetically appealing. AR-coated high-index lenses also perform better at night than uncoated high-index lenses. This is because more light is transmitted, and less glare from oncoming lights is encountered.

Note: There is an easier way to calculate the percentage of light transmitted through a lens using Ultimate Transmission. This will be explained shortly.

Why a Tinted Glass Lens Becomes Darker When Its Plus Power Increases (Lambert's Law of Absorption)

When a lens material contains its tint by having it mixed into the glass or resin material itself, the amount of light transmitted will change with a change in thickness. The amount of change is predictable using Lambert's law of absorption. Lambert's law of absorption states[38] that

1. As light passes through a homogeneous substance of a given thickness, the same percentage of light is absorbed regardless of the intensity of the incident light.

   This means that if a given thickness of absorptive material absorbs 50% of dim light, it will absorb 50% of bright light as well. The same percentage of light will be absorbed, regardless of how dim or bright the light is.
2. The intensity of transmitted light varies as an exponential function of the length of the light path in the absorbing medium.

For example, as the thickness of the absorbing medium doubles, the effect is equal to squaring the transmission factor for the original thickness. If the thickness triples, the effect is cubed, and so on.

Example 22.4

Suppose a 1-mm thick lens has a transmission factor (q) of 0.9. This means that, ignoring reflections, if light strikes the lens, 90% of the light comes out the other side. If surface reflections are ignored, what would the transmission of a lens made of the same material be if it had a 2- mm thickness?

Solution

If the intensity of light entering the first millimeter of lens material is 100%, or 1, the intensity of light leaving the first millimeter is

$$
\begin{aligned}
I_1 &= I_0(q) \\
&= 1(0.9) \\
&= 0.9
\end{aligned}
$$

Next, light enters the second millimeter with an intensity of 0.9. After passing through the second millimeter, the intensity of light leaving the second surface is

$$
\begin{aligned}
I_2 &= I_1(q) \\
&= 0.9(0.9) \\
&= 0.81
\end{aligned}
$$

In other words, the second millimeter absorbs 90% of the light leaving the first millimeter, which was also 90%. Ninety percent of 90% is 81%. (This is the same as 0.9 squared.) Therefore, 81% of the original oncoming light will make it through this 2-mm thick lens.

Expressing Lambert's Law as an Equation

To make Lambert's law into an equation, we see that if

$$I_1 = I_0(q)$$

and

$$I_2 = I_1(q)$$

then

$$I_2 = I_0(q)(q) = I_0(q)^2$$

I_0 is the original amount of incident light, I_1 is the amount of incident light remaining after leaving the first layer, I_2 is the amount remaining after leaving the second layer, and q is the transmission factor for the thickness of the layer. Continuing the logic, we see that if we have x layers, then the amount of incident light remaining after the xth layer will be:

$$I_x = I_0(q)^x$$

and the percentage of light transmitted will be

$$T_x = 100\,[I_0(q)^x]$$

How to Take Reflections Into Consideration When Using Lambert's Law

If reflections are considered, then the amount of incident light that enters the first surface after reflection is

$$I_0 = I - I_R$$

I is the original intensity of entering light, I_R is the intensity of the reflected light, and I_0 is the intensity of light entering the first layer (after reflection).

Total lens transmission will be

$$T = T_x - R_B$$

where T_x is the total percent transmission leaving the last layer (or back of the lens before back surface reflection takes place), R_B is the light reflected from the back surface, and T is the total percentage of light transmitted from the lens with both reflection and absorption considered.

Example 22.5

A tinted crown glass lens has a transmission factor of $q = 0.9$ for each millimeter of lens thickness. If the lens has an index of refraction of 1.523 and is 3.0 mm thick, what is the transmission of the lens?

Solution

The intensity of the light reflected from the front surface of the lens is:

$$\begin{aligned} I_{R(Front)} &= \left[\frac{n' - n}{n' + n}\right] \times I \\ &= \left[\frac{1.523 - 1}{1.523 + 1}\right]^2 \times 1 \\ &= 0.043 \end{aligned}$$

After front surface reflection, the intensity of light entering the lens ("first layer") is

$$\begin{aligned} I_0 &= 1 - 0.043 \\ &= 0.957 \end{aligned}$$

The intensity of light at the back surface of the lens (leaving the last layer) before back surface reflection occurs is

$$I_x = I_0(q)^x$$

or

$$\begin{aligned} I_3 &= (0.957)(0.9)^3 \\ &= 0.698 \end{aligned}$$

The percent transmission leaving the last layer before reflection is

$$\begin{aligned} T_x &= 100(I_x) \\ &= 100(0.698) \\ &= 69.8\% \end{aligned}$$

The intensity of light reflected at the last layer is

$$\begin{aligned} I_{R(Back)} &= \left[\frac{1 - 1.523}{1 + 1.523}\right]^2 \times (0.698) \\ &= (-0.207)^2 \times (0.698) \\ &= 0.043 \times (0.698) \\ &= 0.03 \end{aligned}$$

Therefore, the total percent transmission for light leaving the lens is

$$\begin{aligned} T &= T_x - R_B \\ &= 69.8\% - 3.0\% \\ &= 66.8\% \end{aligned}$$

Ultimate Transmission

The ultimate transmission (T_u) is found by multiplying the transmissions of each element through which light passes to determine ultimately what transmission results.

$$T_u = (T_1) \times (T_2) \times (T_3) \ldots \text{etc.}$$

(such as 3 lenses lined up one behind another.)

Example 22.6

An individual is driving a car with a lightly tinted windshield having a transmission of 85%. He is wearing sunglass clip-ons with a 20% transmission over a pair of lightly tinted spectacle lenses with an 87% transmission. What percentage of incoming light gets through to the eye?

Solution

To find ultimate transmission, multiply all of the transmissions together. In this case,

$$\begin{aligned} T_u &= 0.85 \times 0.20 \times 0.87 \\ &= 0.15 \end{aligned}$$

Therefore, the ultimate transmission of light through this "system" is 0.15, or 15%.

Using Ultimate Transmission to Find Transmission After Surface Reflections

We can use the process of ultimate transmission to find lens transmission when surface reflections are considered. Here is Example 22.2 worked again using ultimate transmission.

Example 22.7 (Example 22.2 Revisited)

Example 22.2 asks, "What percentage of light can we expect an absolutely clear CR-39 plastic lens to transmit if it has an index of refraction of 1.498?" This time find the answer by finding the transmission factors for both front and back surfaces and solve using ultimate transmission.

Solution

Here's how it is done.

1. Find the amount of light reflected from the first surface as a reflection factor.

$$\begin{aligned} I_{R(Front)} &= \left[\frac{n' - n}{n' + n}\right] \times I \\ &= \left[\frac{1.498 - 1}{1.498 + 1}\right]^2 \times 1 \\ &= \left[\frac{0.498}{2.498}\right]^2 \times 1 \\ &= [0.1994]^2 \times 1 \\ &= 0.0398 \end{aligned}$$

(This is exactly the same as the first part of Example 22.2.)

2. Find the transmission factor for the first surface.

This will be:

$$1 - 0.0398 = 0.9602$$

3. Find the transmission factor of the second surface.

$$I_R = \left[\frac{n' - n}{n' + n}\right]^2 \times I$$
$$= \left[\frac{1.0 - 1.498}{1.0 + 1.498}\right]^2 \times 1$$
$$= \left[\frac{-0.498}{2.498}\right]^2 \times 1$$
$$= [0.1994]^2 \times 1$$
$$= 0.0398$$

So again, the transmission factor for the second surface is 0.0398, just like for the first surface. In fact, the transmission factor for the second surface of a lens will always be the same as the transmission factor of the first surface.

4. Now find the ultimate transmission of the lens.

$$T_U = T_{Surface1} \times T_{Lens} \times T_{Surface2}$$
$$= 09602 \times 1 \times 0.9602$$
$$= 0.9220 \text{ or } 92.20\%$$

The lens transmission is 92.20%, which is exactly the same answer as found in the original Example 22.2. Since the lens is clear, the transmission for the material is 100% and the transmission factor of the lens material (T_{lens}) is 1.

If the lens material were to be tinted, it would have a transmission of less than 1. It is a simple matter to use this material transmission factor as T_{lens} and find the total or ultimate transmission for a tinted lens this way.

Opacity

Opacity is the reciprocal of transmission. (When calculating opacity, transmission is not expressed as a percentage.)

$$\text{Opacity} = \frac{1}{\text{Transmission}}$$

Example 22.8

What is the opacity of a lens having 67% transmission?

Solution

Since transmission is not expressed as a percentage, then

$$O = \frac{1}{0.67} = 1.49$$

The opacity of the lens is 1.49.

Example 22.9

Suppose an individual is wearing absorptive spectacle lenses having a transmission of 80%. She gets into a car with a tinted windshield. The windshield has a transmission of 80%. In this situation, what percentage of the light is transmitted to the eye? What would our answer be if expressed as opacity?

Solution

We are seeking the ultimate transmission of the combination of elements. In this case, it is

$$T_u = (T_1) \times (T_2)$$
$$= (0.8) \times (0.8)$$
$$= 0.64, \text{ or } 64\%$$

The opacity of this combination would be

$$O = \frac{1}{T}$$
$$= \frac{1}{0.64}$$
$$O = 1.56$$

Optical Density

Using transmissions makes figuring odd thicknesses difficult. Densities, however, are additive. Optical density is the log of the opacity and is expressed as

$$\text{Optical density} = \log_{10}(\text{Opacity})$$

which is the same thing as

$$D = \log O$$

and also can be expressed as

$$D = \log \frac{1}{T}$$

Since

$$\log \frac{1}{T} = \log 1 - \log T$$
$$= 0.0 - \log T$$

Therefore,

$$D = -\log T$$

Example 22.10

If a lens has a transmission of 0.90 for each millimeter of thickness, what is its optical density per 1/10 mm, and what is the transmission for 1/10 mm?

Solution

First, we find the optical density for 1 mm.

$$D = -\log T$$
$$= -\log 0.90$$
$$= 0.0457575$$

Now, we can find the optical density for 1/10 mm. Density (D) for 1/10 mm is

$$\frac{0.0457575}{10} = 0.00457575$$

The optical density for 1/10 mm is 0.00458.

To find the transmission for 1/10th mm, we convert from optical density back to transmission. We know that

$$D = -\log T$$

and that the density of 1/10th mm is 0.00458.

Therefore,

$$-\log T = 0.00458$$

So

$$\log T = -0.00458$$

Taking the antilog of −0.00458 we find that

$$T = 0.99$$

So 1/10 mm has a transmission of 99%.

Laser Protective Eyewear is Specified in Optical Density

When transmission of a lens is a very small number, optical density of the lens will be large. As an example, when the transmission of a lens is 1% (or 0.01), the density of that lens is 2.0. For this reason, many times, occupational safety tints and especially laser safety tints are specified in terms of optical density instead of percent transmission. This way, the higher the optical density number, the more protection it provides. Care should be taken not to interpret an optical density curve as a transmission curve. Otherwise, one may get the false impression that the areas of highest protection are permitting a large transmittance.

As an example, in Figure 22.25, laser protective eyewear used around Argon lasers is shown to have a high optical density for wavelengths from 200 to 532 nm. This high optical density protects the wearer in the wavelength zone for Argon lasers. However, the optical density drops back to almost zero above 600 nm. Light above 600 nm can be seen easily. In a graph that uses optical density such as the one shown in Figure 22.25, the high areas of the graph indicate the wavelength areas of most protection.

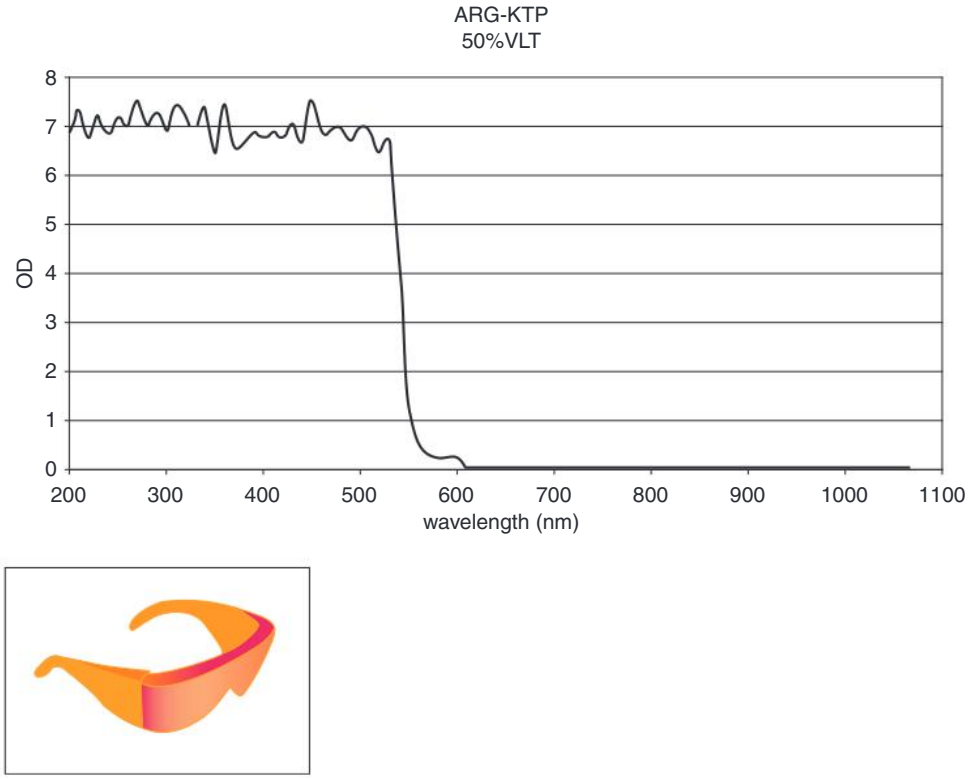


Figure 22.25 Laser protective eyewear uses optical density instead of transmission to specify the absorbency of the filter. The higher the density, the more the radiation is absorbed. (From http://www.noirlaser.com/filters/arg.html, NoIR Laser Co, LLC, 6155 Pontiac Trail, South Lyon, MI, 48178, 8/16/2005.)

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PROFICIENCY TEST

(Answers may be found in the back of the book.)

1. True or false? The longer the wavelength of the ultraviolet (UV) rays, the greater the likelihood of biologic damage.
   a. True
   b. False
2. True or false? Single-occurrence, high-level amounts of UV radiation can be damaging, but the eye is able to recover from long-term, low-level amounts of UV exposure without being affected.
   a. True
   b. False
3. True or false? A person's ability to work effectively under a situation of reduced illumination increases with age.
   a. True
   b. False
4. True or false? When a tint and an antireflective (AR) coating are both desired, plastic lenses should be dyed before they are AR coated.
   a. True
   b. False
5. True or false? Continued unprotected high exposure to sunlight over an extended number of days will increase the time needed for the eye to regain its full dark adaptation.
   a. True
   b. False
6. True or false? Yellow tints help nighttime driving because they eliminate blue haze.
   a. True
   b. False

7. True or false? With AR coatings, it is possible to have any one of a range of reflex colors or no reflex color at all and still produce an efficient coating.
   a. True
   b. False
8. True or false? An AR coating will make a lightly tinted lens perform better at night than it otherwise would perform with the tint but no AR coating.
   a. True
   b. False
9. True or false? The process of adding an AR coating to a tinted plastic lens sometimes changes the color of the tint.
   a. True
   b. False
10. True or false? AR coating the back surface of a pair of sunglasses is not advisable, because it lets more light through the lens.
    a. True
    b. False
11. True or false? An AR-coated lens is best cleaned in office by using an ultrasonic cleaner.
    a. True
    b. False
12. True or false? There is no such thing as a "glare control dye."
    a. True
    b. False
13. True or false? Glare control–type lenses will not cause a decrease in scores on standardized color testing for color defectives.
    a. True
    b. False
14. All of these lenses are vacuum coated to the equivalent of a "gray #3" tint. Which lens will be the darkest?
    a. +7.00 D
    b. Plano
    c. −7.00 D
    d. It depends on whether edge or center is being considered.
    e. All will be equally dark.
15. Which UV radiation has the longest wavelength?
    a. UVA
    b. UVB
    c. UVC
16. Rank the following lenses in order, beginning with the lens that absorbs the most short-wavelength visible and UV radiation and concluding with the lens that absorbs the least short wavelength visible and UV radiation.
    1. Coated polycarbonate lenses
    2. Crown glass lenses
    3. CPF 550 lenses
    4. Uncoated CR-39 plastic lenses
    a. 2,4,1,3
    b. 3,1,2,4
    c. 1,4,2,3
    d. 3,1,4,2
    e. 3,4,1,2
17. Which of the characteristics listed below is most applicable to a lens with a light pink tint?
    a. blue absorbing
    b. advisable for night driving
    c. selective absorption of red
    d. good UV and infrared (IR) absorption
    e. even absorption across the visible spectrum
18. Which of the characteristics listed below is most applicable to a lens with a yellow tint?
    a. blue absorbing
    b. advisable for night driving
    c. selective absorption of red
    d. good UV and IR absorption
    e. even absorption across the visible spectrum
19. Which of the characteristics listed below would be the most appropriate statement for a lens with a gray tint?
    a. It is recommended for bright, hazy days.
    b. It is good for people with color vision deficiency.
    c. It is highly absorbing of yellow light.
    d. It has its highest transmission of visible light in the middle of the visible spectrum.
    e. It selectively cuts out blue light.
20. Which of the following characteristics would be the most appropriate statement for a lens with a green tint?
    a. It is recommended for bright, hazy days.
    b. It is good for color defectives.
    c. It is highly absorbing of yellow light.
    d. It has its highest transmission of visible light in the middle of the visible spectrum.
    e. It selectively cuts out blue light.
21. A person has new spectacle lenses and has been wearing them for a month. She now decides she would like to have them AR coated. The lenses are lightly scratched. If the lenses are then AR coated,
    a. the scratches will be more evident.
    b. the scratches will not show up as much.
    c. the AR coating will not affect the appearance of the scratches.
22. A glass absorptive lens with the tint in the glass has a lighter horizontal area running the full width of the lens. What might the prescription be?
    a. −4.00 sphere
    b. +4.00 sphere
    c. Plano −4.00 × 180
    d. Plano +4.00 × 180
    e. +4.00 −4.00 × 135
23. First-generation, single-layer AR-coated lenses had a bluish-purple cast when they were held at certain angles. This occurs because, to most nearly fulfill path and amplitude conditions and still achieve a maximal antireflective effect over a large area of the visible spectrum, a specific wavelength had to be chosen. That wavelength corresponded to which color?
    a. yellow
    b. blue
    c. red
    d. bluish-purple
    e. All wavelengths equally fulfill path and amplitude conditions.
24. True or False? Sometimes you can see a reflection of the dashboard of a car reflecting from the windshield. Polarizing sunglasses will reduce the visibility of these dashboard reflections more than regular sunglasses having the same percent transmission as the polarizing sunglasses.
    a. True
    b. False
25. The problem of annoying internal lens reflections occurs most often in
    a. high plus-powered clear lenses.
    b. low minus-powered clear lenses.
    c. scratch-resistance–coated (SRC) clear lenses.
    d. antireflection-coated clear lenses.
    e. sun lenses.

26. A polarizing ophthalmic lens should be oriented so as to eliminate
a. vertically vibrating waves.
b. horizontally vibrating waves.
c. obliquely vibrating waves.
d. all vibrating waves.
e. Orientation is unimportant.

27. If a lens has an index of refraction of 1.66, what is the ideal index of refraction for a single-layer AR coating?
a. 0.307
b. 1.167
c. 1.288
d. 1.755

28. Two lenses are placed back-to-back. One has a transmission of 50%; the other has a transmission of 40%. What percent transmission do they have together?
a. 10%
b. 20%
c. 25%
d. 45%
e. 90%

29. Four AR-coated neutral density filters are lined up one behind another. The first has a 55% transmission, the second has a 91% transmission, the third has a 28% transmission, and the last has a 78% transmission. If we assume that the AR coatings have extinguished all front and back surface lens reflections, what percent of light will be transmitted by the entire series? (Give your answer to the nearest whole percent.)
a. 11%
b. 7%
c. 4%
d. 1%
e. To the nearest whole percent, no light will be transmitted.

30. If a perfectly clear, uncoated lens has an index of refraction of 1.73, what percent of the incoming light would be transmitted out the back of the lens?
a. 81.0%
b. 86.1%
c. 88.1%
d. 91.6%

31. A lens has a transmission of 41%. What is the opacity of the lens?
a. 0.024
b. 0.387
c. 1.61
d. 2.44

23

Lens Materials, Safety Eyewear, and Sports Eyewear

LENS MATERIALS

With several choices available for lens materials, the practitioner needs to know material characteristics so that a proper match between the needs of the wearer and the best possible material occurs. Ophthalmic lenses are made from glass or plastic. Glass lenses are sometimes referred to as *mineral* lenses, whereas if a lens is made from plastic, it is said to be from *organic* material.

Crown Glass

Glass was the material used for spectacle lens wear for several hundred years. Glass works well for ophthalmic materials because it resists scratching and is not easily affected by environmental factors. The main disadvantages of glass are weight and impact resistance. To pass U.S. requirements for impact resistance, glass must be hardened.

The most commonly used clear glass lens material is made from a type of *crown glass* having an index of refraction of 1.523. This material is low in chromatic aberration.

High-Index Glass

There are higher index glass lens materials available that will reduce lens thickness for higher powered prescriptions. Unfortunately, high-index glass lenses are composed of materials with a higher specific gravity, making them heavier.

Plastic Lenses

CR-39

For years the most commonly used plastic lens material was CR-39. CR-39 was developed by PPG Industries. "CR" stands for Columbia Resin, and the number 39 denotes the type of Columbia Resin used. CR-39 lens material processes well in the laboratory.

When comparing the weight of CR-39 plastic lenses with glass, we find that CR-39 lenses are roughly half the weight of crown glass. Surprisingly enough, when hit with low-velocity large-mass objects such as a softball, chemically tempered glass lenses perform somewhat better than CR-39 lenses. For smaller high-velocity sharply pointed objects, CR-39 lenses perform better than chemically tempered glass. (It should be noted that glass is weakened more by scratching than is CR-39 plastic.) Keep in mind, however, that for impact resistance, there are a number of other plastic lens materials that outperform both chemically tempered glass and CR-39 plastic. Impact resistance will vary according to the type of plastic used.

CR-39 plastic lenses do not fog up as easily as glass lenses.

Although it seems counterintuitive, welding or grinding spatter will pit or permanently stick to glass lenses, but it does not adhere to plastic lens material.

Higher Index Plastics

CR-39 plastic lenses have an index of refraction of approximately 1.498. This is the lowest refractive index material used for spectacle lenses. For minus lenses of equal powers and center thicknesses, the higher the index of refraction of a lens material, the thinner the lens edge can be made. Therefore, higher index plastic lens materials will have both a weight and a thickness advantage over CR-39. They are an attractive alternative.

Higher index plastic comes in a variety of choices. When considering the virtues of a higher index lens, the materials should not be compared on the basis of index of refraction alone but also on the basis of weight, impact resistance, finished lens thickness, Abbé value (chromatic aberration), and ease of production. Table 23.1 gives a comparison of some of these characteristics for a few representative materials.

Table 23.2 gives a summary of the impact-resistance characteristics for several currently available lens materials.

Polycarbonate

Polycarbonate lens material is soft and requires an antiscratch coating. However, the very softness of the material contributes to its high-impact resistance. Instead of breaking on impact, the softer polycarbonate material is more likely to absorb a blow and just dent. When safety is the primary concern, polycarbonate has traditionally been the number one choice. Safety is a primary concern for children, monocular lens wearers (people with good acuity in one eye only), and those who are purchasing safety or sports eyewear.)

Because polycarbonate lenses are so much safer than conventional lenses, the eyewear purchaser should be informed of the availability of safer lens materials and given the opportunity to choose a lens that affords better protection.

Trivex

Trivex lens material is a very impact-resistant lens material. It was developed by PPG Industries, the developers of CR-39 material. Trivex processes fairly well and takes a lens tint easily. The lens material was originally for military use as a plastic material to provide good optics and excellent safety characteristics for windows in combat vehicles.[3] PPG Industries promotional materials attribute the "tri" in Trivex to a "tri-performance" lens material; meaning it offers a triple combination of superior optics, impact resistance, and being ultra-lightweight.

Trivex rivals polycarbonate in impact resistance. It is the lens of choice for drill-mounted lenses because it does not crack or split at the drilled hole. Some laboratories will warrant no other material than Trivex for drill-mounted lenses.

The lens is very lightweight, having a density of 1.11. Even though the index of 1.53 is just a bit higher than crown glass, it may be thinned

TABLE 23.1 A Representative Comparison of Lens Materials

Lens Material	Refractive Index (n)*	Density†	Thickness‡ (Minus Lens Center Thickness)	Abbé Value§
CR-39 plastic	1.498	1.32	2.0	58
Crown glass	1.523	2.54	2.0–2.2	59
Trivex	1.532	1.11	1.0–1.3	43–45
Spectralite	1.537	1.21	1.5	47
Polycarbonate	1.586	1.22	1.0–1.5	29
Polyurethane	1.595	1.34	1.5	36
Corning Clears 16 (glass)	1.60	2.63	1.5	42
High-Index plastic	1.66	1.35	1.0–1.7‖	32
	1.71	1.4		36
Thin & Lite 1.74 High-Index plastic	1.74	1.46	1.1	33
High-Index glass[9]	1.7	2.97	2.0–2.2	31
	1.80	3.37		25
	1.90¶	4.02		30.4

*The higher the refractive index for lenses of equal center thicknesses, the thinner the edge of a minus lens will be.
†For an equal volume of lens material, the lower the density is, the lighter the material.
‡Lens thickness is based on the thinnest lens that will maintain both U.S. impact resistance requirements and stability (will not warp). Thicknesses are approximate and may need to vary, depending upon lens coatings used.
§The higher the Abbé value is, the less the chromatic aberration.
‖Depends upon if lenses are single-vision stock or surfaced and whether antireflection coated.
¶This glass lens of index 1.90 cannot be chemically tempered for impact resistance and will not pass Food and Drug Administration requirements.

TABLE 23.2 Relative Impact Resistance of Various Ophthalmic Materials

Lens Material	Comments
Untreated crown glass	Because of Food and Drug Administration regulations, untreated crown glass is not used for ophthalmic eyewear in the United States.
Heat-treated crown glass	Heat-treated glass loses much impact resistance when it is scratched. In fact, when compared for the impact of small, high-velocity objects, a badly scratched untreated glass lens will be more impact resistant than a badly scratched, heat-treated lens.
Chemically tempered crown glass	Against the impact of large, slow-moving objects, such as a softball, chemically tempered crown glass lenses are more impact resistant than CR-39 plastic. When compared to the impact of small, high-velocity objects, however, the CR-39 plastic lens is the more impact resistant.
CR-39 plastic	In general, an uncoated CR-39 lens ranks better than the lenses shown above. If this lens is coated, however, the impact resistance tends to be reduced. Just how much depends on the type of coating used. However, some newer coatings that can increase impact resistance are emerging.
High-index plastic	High-index plastics are made from a variety of materials and, although they vary in their impact resistance, have been classed as only being as strong as CR-39.[2] Keep in mind that there are subgroups in this category. Many of the newer high-index plastics perform well enough to be thinned to 1.0- or 1.5- mm thickness. As with CR-39, impact resistance of high-index lenses is decreased with the addition of antireflection coatings. Polyurethane lenses appear to perform fairly well in impact resistance.
Polycarbonate, Trivex	Impact resistance for polycarbonate and Trivex lens materials exceeds other commonly used prescription lens materials. Antireflection coating does reduce impact resistance of these lenses by varying degrees, depending upon the type of projectile impacting it.

to 1 mm so that thickness and weight are seldom an issue. The Abbé value of 43–45 is less than CR-39 but higher than its rival, polycarbonate. It maintains a good resistance to damage from chemicals.

Laminated Lenses

Lenses that are made from two or more layers of material are called *laminated lenses*. Lamination can be used for several purposes. Before dyed plastic lenses, clear glass lenses were sometimes laminated with a thin layer of tinted glass to give an even tint across the lens. Polarizing lenses have a stretched polarizing film sandwiched between two layers of regular lens material to cut out reflected glare. Lamination can also be used to increase impact resistance.

Effect of Lens Coatings on Impact Resistance

When a plastic lens is either scratch resistance coated or antireflection (AR) coated, the impact resistance of the lens normally decreases. This seems opposite to what would be expected.

Both scratch resistance and AR coatings are harder than the plastic lens material to which they adhere. When a lens breaks, the break starts at the weakest point. If a plastic lens is hit by an object, the lens may flex but may not break. If the coating is harder than the lens, however, as the lens flexes, the harder (more brittle) coating cracks before the uncoated lens. When the coating is strongly bonded to the lens, the energy that is concentrated in the first crack is released. The released energy travels through the lens and may cause it to break.

The weakening of a plastic lens by an AR coating is not limited to CR-39 material. Weakening would be expected to occur in some degree with other lens materials that are softer than the more brittle AR coating. Although the highest impact-resistant materials lose some impact resistance when coated, they have enough reserve strength to be able to remain safe even with coating. (At the time of this writing, newer lens coatings are emerging that promise to increase the impact resistance of the material being coated.)

Effect of Surface Scratches on Impact Resistance

A scratched lens surface reduces impact resistance. The scratch introduces a weak spot on the lens and creates a sort of "fault line." The scratch provides an easy area for stress to build during impact, making breakage more likely. To better imagine how this works, think about how panes of glass are "scored" with a diamond so that they may be broken along the scored line.

Contrary to intuition, scratches on the back surface of a lens will reduce lens impact resistance *more* than front surface scratches. Glass or CR-39 lenses with front surface scratches were reduced in impact resistance by 20%, whereas CR-39 lenses with back surface scratches were reduced in impact resistance by 80%.[4]

GENERAL EYEWEAR CATEGORIES

We can divide eyewear into three broad categories:

- *Dress Eyewear*
  Dress eyewear is eyewear that is designed for everyday use.
- *Safety Eyewear*
  Safety eyewear is designed to meet higher standards of impact resistance since it will be worn in situations that could be potentially hazardous to the eyes.
- *Sports Eyewear*
  Sports eyewear is designed to protect the eyes and/or enhance vision in specific sports situations. What is appropriate will vary dramatically, depending upon the sport.

REQUIREMENTS FOR DRESS EYEWEAR

There are a number of industry and government agencies that have a direct impact on the business of eyewear. All are important to the dispenser in ensuring that the wearer is receiving a product that is within the expectations of the ophthalmic industry and government regulatory agencies. The following sections list the agencies involved and how they affect the dispensing of eyewear.

Food and Drug Administration

Impact resistance requirements for dress ophthalmic lenses in the United States have not always existed. In certain other countries in the world, there still may not be such requirements. For example, it may be allowable to surface glass lenses as thin as 0.3 mm and still have the lenses be wearable. The lenses look wonderfully thin and are still optically excellent, but they afford little protection for the eyes. In many situations, they may end up becoming a hazard to the wearer.

In 1971 the U.S. Food and Drug Administration (FDA) began mandating impact resistance for dress ophthalmic lenses. Since then, all eyeglass and sunglass lenses must be impact resistant except when the optometrist or physician finds that the lenses will not otherwise fulfill the patient's visual requirements. If the lens cannot be rendered impact resistant and no other lens will satisfy visual requirements, this must be recorded in the patient's record and the patient notified in writing.

When May Nonimpact-Resistant Lenses Be Dispensed?

Some dispensers may assume that a written agreement having the patient assume responsibility makes it possible to dispense nonimpact-resistant lenses. This does not ensure freedom from liability. Here is the way the FDA responds to three frequently asked questions on dispensing nonimpact-resistant lenses.[5]

Q. Under what circumstances may retailers dispense lenses that are not impact resistant?

A. Lenses that are not impact resistant may be dispensed when a physician or optometrist determines that impact-resistant lenses will not fulfill the visual requirements of a particular patient. The physician or optometrist must direct this in writing and give written notification to the patient.

Q. Can a retailer supply a nonimpact-resistant lens if a patient requests it or if the patient/customer agrees to assume all responsibility?

A. You may only provide nonimpact-resistant lenses when the physician or optometrist determines that impact-resistance lenses will not fulfill the visual requirements of the patient. In such cases, the physician or optometrist must give notice in writing to the patient, explaining that the patient is receiving a lens that is not impact resistant.

Q. Are there situations in which a retailer may provide nonimpact-resistant lenses?

A. The FDA believes it is appropriate to exercise its enforcement discretion with respect to a retailer who provides nonimpact-resistant lenses in an emergency situation with the knowledge and consent of the patient and the eye care professional. For example, a surgeon's eyeglasses break just before a scheduled surgery and the lenses need to be replaced immediately. If there is no alternative, the FDA would consider exercising enforcement discretion with respect to a retailer who may provide the surgeon with nonimpact-resistant lenses on a temporary basis with the knowledge and consent of the patient and eye care professional.

Must Dress Ophthalmic Lenses Have a Minimum Thickness?

Formerly, dress ophthalmic lenses had a minimum thickness requirement of 2.0 mm. Now, there is no thickness requirement regardless of lens material. Impact resistance requirements are performance based and the lens must be capable of withstanding a predetermined amount of impact. If that requirement can be met with lenses that are thinner than 2.0 mm, the lens is acceptable. Today, there are many lenses that can meet current impact resistance requirements and still be below 2.0 mm, including some types of glass lenses.

Impact Resistance Test Requirements

The standard "referee test" for determining impact resistance suitability for dress ophthalmic lenses is the drop ball test. This test is very specific in how it should be administered. However, the FDA states that this does not inhibit the lens manufacturer from using equal or superior test methods to test for impact resistance.

The Drop Ball Test

To be judged acceptable, a lens is first placed front side up on a neoprene gasket. It must be capable of withstanding the impact of a 5/8-inch steel ball weighing 0.56 oz. that is dropped from a height of 50 inches (Figure 23.1).

When Should the Drop Ball Test Be Performed?

Glass lenses must be tested after the lens has been edged and hardened and before it is placed in the frame. Plastic lenses may be tested in the "uncut-finished" stage before they have been edged.

Drop-Ball Testing of Glass Lenses

With few exceptions, all glass lenses must be hardened *and* individually subjected to the drop ball test. Only lenses that could be damaged by the test are exempt. These lenses must still be hardened but do not need to be tested.

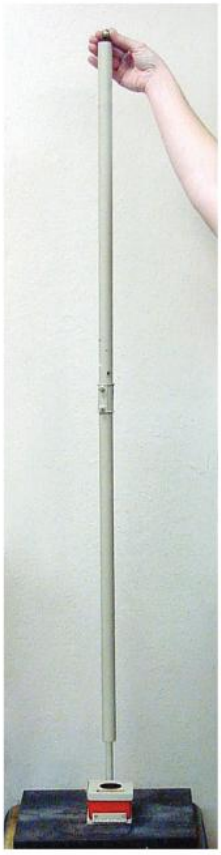

Figure 23.1 A drop-ball tester drops a steel ball on the front surface of a lens from a height of 50 inches.

Individual Versus Batch Testing

Batch testing is the practice of selectively testing a statistically significant number of lenses in a manufactured group. This avoids having to individually test lenses that could sustain damage by the test itself. The practice of batch testing is permitted for:

1. Plastic lenses.
2. Nonprescription lenses, such as mass-produced sunglass lenses.

(Glass, plano-powered sunglass lenses that are individually produced in a finishing laboratory must still be individually drop-ball tested.)

Who Does Batch Testing?

The lens manufacturer normally does batch testing. When this is done, plastic lenses that are edged in a finishing laboratory do not have to be individually tested or batch tested in the finishing laboratory.

If the lens is altered after having been received from the manufacturer, as when it is sent out for AR coating, then the lens is no longer warranted by the original lens manufacturer. The coating laboratory that does AR and color coatings is responsible for batch testing lenses being coated in their laboratory.

Defining "Manufacturer"

There are a large number of participants involved in the process of making a pair of glasses. It is possible that one company may be responsible for all steps in the manufacturing process. However, there may be times when one company makes the lenses, another surfaces the lenses, a third edges the lenses, and, in certain circumstances, yet another could coat the lenses. Who then is the manufacturer of the finished eyeglasses? Here is how the FDA defines the manufacturer and the manufacturer's responsibilities:

> *"The manufacturer must perform the test for impact resistance (21 CFR 801.410(d)(1)). Manufacturer is defined under 21 CFR 820.3 (o) and would include the person (or firm) who puts the lens in the form ready for its intended use or who alters the physical or chemical characteristics of the lens by grinding, heat treating, beveling, applying scratch resistant coating, applying antireflection coating, cutting, or other pertinent actions. Manufactures of all plastic lenses and nonprescription glass lenses may test at the uncut finished or finished stage while glass prescription lenses must be tested at the finished stage. Retail laboratories that perform some or all of these processes are manufacturers. For the purpose of 21 CFR 801.410, the term "manufacturer" also includes a company that imports impact resistant lenses for eyeglasses, or who imports finished eyeglasses or sunglasses for resale. (21 CFR 801.410(g))"*[5].

So where does this leave the eye care provider with an in-house lens surfacing, casting, or finishing (edging) lab? Here is how the FDA answers the question, "Do the impact test regulations apply to retail stores that fabricate lenses?"

> *"FDA considers retail stores that fabricate lenses by coating and/or surfacing to be manufacturers of impact-resistant lenses. Therefore, such retailers must document impact resistance (21 CFR 801.410(c)(3)). You may perform impact testing on site or you may contract with a third-party testing lab. Retail stores that only perform edging are not considered manufacturers."*[5]

So, if the retail eye care practitioner does surfacing, molding, or coating of lenses, then they must document when and how their impact testing is done according to FDA procedural requirements, but if only edging of lenses is done, then this documentation is not required. This is likely because when plastic lenses are edged, this testing has been previously done and documented.

If glass lenses are edged, then these lenses are not batch tested and are to be individually tested in the retail lab, assuming the lab edges glass lenses. In this case, all record keeping required of retail lab manufacturers must be recorded and kept for 3 years.

The Dispenser's Role in Record Keeping

Here is what the FDA says in question-and-answer format regarding retailer record keeping. The question states, "What information is the retailer required to keep on individuals purchasing eyeglasses or sunglasses?" The answer given is:

> *"There are no requirements for the retailer to keep and maintain the names and addresses of individuals purchasing nonprescription eyeglasses and sunglasses at the retail level under 21 CFR 801.410. However, the retailer should consult state law to determine relevant state requirements for the sale of prescription lenses."*[5]

It should be noted that the answer to this question only applies to glasses sold and not to doctors' examination records.

Federal Trade Commission

The Federal Trade Commission (FTC) was established to prevent unfair business practices such as deceptive advertising and monopolies. In the late 1970s the FTC began to look at the ophthalmic industry. After two series of investigative studies known as Eyeglasses I and Eyeglasses II, prescription release rules were formulated for spectacle and contact lenses. The spectacle lens aspects of these rules will be considered here.

Eyeglasses I

In 1978 the FTC concluded their Eyeglasses I investigative study with a spectacle lens prescription release rule. This rule requires that patients be given a copy of their spectacle lens prescription so that they may fill that prescription wherever they desire. The prescription is to be given immediately after the eye examination is completed, whether or not the patient asks for the prescription. A new written prescription is also to be given even if the change is too small to require a change in eyeglasses or if there is no change at all since the previous eye examination. The Eyeglasses I prescription release rule listed minimal information to be included in the prescription: sphere power, cylinder power and axis (if any), prism (if any), and the signature of the prescribing optometrist or physician.[6]

Eyeglasses II

In 1989 the FTC did a more complex investigative study that was primarily concerned with restrictions on practice ownership by people who were not optometrists, ophthalmologists, or opticians.

Eyeglasses II rules no longer list minimal information needed for a spectacle lens prescription. Therefore, prescribers are at liberty to include whatever they consider important for the patient's visual welfare on the prescription. This could include lens material, specific lens styles, and instructions for wear. For example, suppose a patient has one eye with normal vision and one with very little usable vision. In this instance in which eye protection is important, including polycarbonate lens material on the prescription may reduce the possibility of prescriber liability in the event of eye injury.

An expiration date is usually a part of the prescription. Although duplication of an existing pair of glasses may be done without restrictions, the dispenser has an ethical obligation to inform such a person of the importance of regular eye examinations. Eye disorders and diseases are not always accompanied by pain and so may not be readily apparent. Contrary to what is often believed, state laws do not set a time limit, such as 2 years, on the length of time an eyeglass prescription may still be filled. "Most states do not have a requirement for an expiration date on spectacle prescriptions, although they do not prohibit a doctor from indicating one. Where states do have laws, the concern has been primarily to regulate how short the time limit should be, not how long. In states in which this subject is not regulated, it is left to the discretion of the doctor.[7]

Like Eyeglasses I, Eyeglasses II continues to prohibit disclaimers written on the prescription such as "Not responsible for accuracy of ophthalmic prescription materials obtained from third-party dispensers."

Here are some other points about which the FTC would like to remind eye care providers:[8]

- Prescribers cannot require patients to buy eyeglasses from them as a condition of performing an eye exam.
- Prescribers cannot require that patients buy eyeglasses as a condition of providing a copy of the prescription.
- Prescribers cannot place a liability waiver on the prescription. They also cannot require patients to sign a waiver or require them to pay additional fees in exchange for a copy of the prescription.

Prescribers may require patients to pay for their eye exam before giving the patient a copy of the prescription, but only if they also require immediate payment from patients whose exams reveal no need for glasses, contacts, or other ophthalmic goods.[8]

SAFETY EYEWEAR

Safety eyewear has been an extremely important factor in reducing eye injuries. Now that safety eyewear is a must in industry, eye injuries most often occur because of a failure to wear eye protection at the time of the accident or because the wrong kind of eye protection was worn. Today, the most likely eye injury situation occurs when workers are wearing safety eyewear without side shields.[9]

ANSI Establishes and OSHA Regulates Safety Eyewear Standards

The Occupational Safety and Health Administration (OSHA) is the federal agency charged with regulating safety practices in the workplace and in educational settings. OSHA rulings have the same power as law. Compliance visits to a workplace are often unannounced, and violations of OSHA regulations discovered at the time of the inspection can result in both mandates to correct the violation and substantial fines.

Rather than beginning anew with a set of eye and face protection requirements, OSHA has chosen to adopt the American National Standards Institute/International Safety Equipment Association (ANSI/ISEA) Z87.1 standard already set forth by ANSI/ISEA. Therefore, the ANSI/ISEA Z87.1 standard is a federal requirement.

Because it would be difficult to list every situation in which eye protection must be worn, OSHA has chosen to place the burden on education and industry by simply stating that "Eye and face protection must be provided whenever necessary to protect against chemical, environmental, radiological, or mechanical irritants and hazards.[10]"

(The Z87.1 standard for safety eyewear is not the same as the *ANSI Z80.1 American National Standard for Ophthalmics—Prescription Ophthalmic Lenses—Recommendations.* The ANSI Z80.1 standards, as discussed in Chapter 6, are just what the title says; they are recommendations and not requirements.)

Impact Ratings for Safety Eyewear

At the time of this writing, the most recent safety eyewear standard is *ANSI/ISEA Z87.1–2020 American National Standard for Occupational and Educational Personal Eye and Face Protection Devices.* There are two different thickness requirements for spectacle lenses. If the lenses are made from material that is more impact resistant and can pass the necessary tests for a 2- mm minimum thickness, these spectacles are referred to as *impact rated.* Lenses requiring more thickness must still pass minimum tests but are not impact rated.

Requirements for Nonimpact-Rated Prescription Safety Eyewear

Because there are two levels of safety eyewear, why would anyone want to wear a lens that was not impact rated when impact-rated lenses are available? Of the two levels of safety eyewear available, in most situations it is desirable to have an impact-rated lens, since it produces a thinner, lighter, and safer lens. However, in work situations in which workers may be cleaning their glasses constantly (e.g., in places with a lot of abrasive dust), polycarbonate or other more impact resistant lenses are prone to scratches. Therefore, glass lenses that are more able to withstand scratching might be a better option. Badly scratched lenses are irritating to wear and, if vision is affected, may create a safety hazard. So, even though glass lenses are not able to pass the impact-rated requirements, in the absence of a material that has the same scratch resistance, lenses that are not impact rated may be the more appropriate lens. That said, impact-rated lenses are definitely the better choice.

Thickness Requirements for Nonimpact-Rated Prescription Lenses

For a number of years, thickness requirements for prescription safety lenses have been a minimum of 3.0 mm. The exception has been for plus lenses that have a power of greater than or equal to +3.00 D in the most plus

TABLE 23.3 American National Standards Institute[11] Z87.1 Lens Marking Requirements*

Lens Type	Requirement	Impact-Rated Example
Clear lenses	Manufacturer's monogram (such as Ω, for example) and a + if impact rated	Ω+
Tinted (absorptive) lenses except for special purpose lenses	Manufacturer's monogram, an L (for visible light filter) followed by a shade number, and often a +	Ω + L1.5
Photochromic lenses	Manufacturer's monogram, a V for variable shade, and sometimes a +	Ω + V
Special purpose lenses Special purpose lenses provide eye protection while performing visual tasks that require unusual filtering of light. Examples include lenses used for a unique job, as well as lenses prescribed by an eye specialist for particular vision problems.	Manufacturer's monogram, an S for special purpose, and sometimes a +	Ω + S
Other lens markings may include but are not limited to:	W for welding filters—followed by a shade number U for a ultraviolet filter R for an infrared filter X for antifog lenses	

*All markings must be legible and permanent and placed so that interference with the vision of the wearer is minimal.

meridian of the distance portion of the lens. The reason for the exception is because high plus lenses are much thicker in the center. Therefore these lenses may be thinned to a 2.5-mm minimum edge thickness and still remain strong because of their overall thickness. These standards remain as thickness requirements for current Z87 safety eyewear.

Testing Requirements for Nonimpact-Rated Prescription Lenses

Safety lenses that are not impact rated are tested with drop-ball testing in much the same way as dress ophthalmic lenses are tested. However, instead of a 5/8-inch steel ball dropped from a height of 50 inches, nonimpact-rated safety lenses must withstand a 1-inch steel ball.

Marking Requirements for Nonimpact-Rated Prescription Lenses

Nonimpact-rated safety lenses must be marked with the manufacturer's logo or identifying mark. The markings are applied after edging. Marks on the surface of the lens should be out of the line of sight. They usually appear at the center of the top of the lens or in the upper, outer corner. If the lens is other than a clear lens, it may require additional markings. A summary of these marking requirements is found in Table 23.3. Remember, a lens that is thick enough to be classed as a safety lens and strong enough to pass safety lens impact testing is not acceptable as a safety lens until it is marked with the required manufacturer's identification.

Requirements for Impact-Rated Prescription Safety Eyewear

In order to qualify as impact rated, a prescription safety lens must pass (1) a high mass impact test, (2) a high velocity impact test, and (3) a penetration test. It must have a minimum thickness of 2 mm at the thinnest point on the lens. There are no drop ball test requirements if these three tests are successfully passed at the required minimum thickness. These tests are not performed on every lens. Instead they may be batch tested by the manufacturer using a plano-powered 2- mm thick lens.

Impact-Rated Testing and Marking Requirements

Here are the tests impact-rated lenses must pass.

1) Impact rated safety lenses must pass a *high mass impact test.* In this test, a pointed, conical-tipped projectile 1 inch in diameter and weighing 17.6 oz is dropped 51.2 inches through a tube and onto the front surface of the lens (Figure 23.2).
2) Lenses must also pass a *high velocity impact test.* In this test, the lens is mounted on a special holder and must be capable of withstanding the force of a 6.35 -mm (1/4 -inch) diameter steel ball traveling at 150 ft/s or a 6 -mm steel ball traveling at 167 ft/s (Figure 23.3).
3) The *penetration test* consists of a weighted needle (44.2 g total weight) dropped from a height of 50 inches.

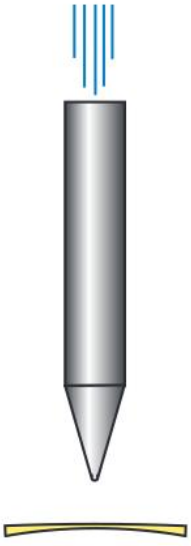

Figure 23.2 In the *high mass impact test,* a pointed, 1-inch diameter projectile is dropped onto a safety lens or frame.

If, in any of these tests, the lens fractures, has any of its inside surface detach, or has a full-thickness penetration, then the lens fails.

If the lens does not fail, any prescription lens made from the same material, at the same 2- mm or greater minimum thickness, having the same coatings, and produced by the same processes will then be considered impact-rated. These lenses may then be marked with the + identity mark. The + mark, along with the manufacturer's logo, indicates that the lens is impact-rated. (See Table 23.3 for these and other required safety lens and frame markings.)

Safety Frames

Safety Frame Testing

Safety frames must withstand certain specific impact tests that are not required of normal dress frames. Frames are placed on a head model. When impact occurs, the frame cannot break. Nor can the frame or lens come into contact with the eye.

One test used to test safety frames is the same *high mass impact* test. The other is the *high velocity impact test*. These are the same tests described previously for lenses. Each frame type is tested with a − 5.00 D lens and a + 5.00 D lens. The frames are tested at multiple locations. To pass, neither the frame nor the lens can break, nor can the lens come out of the frame.

Marking Safety Frames

There is a clear distinction between "dress" frames and safety frames. *Dress* frames are worn for everyday purposes. No matter how sturdy the construction of a dress frame, it is still not suitable as a safety frame unless it passes the required frame tests and is specifically marked as being a safety frame. Required markings are size, the manufacturer's trademark, and Z87–2 indicating compliance with ANSI Z87 standards. (The "2" in Z87–2 means that the frames have been tested with impact-rated 2 -mm lenses.) (Box 23.1).

Small-sized safety frames are tested on a smaller head-form model. These must also be marked with an H on the frame. For small rimless or semirimless safety frames, the H will be marked on the lens. (Although it might seem that rimless and semirimless frames should not be permitted as safety frames, these rimless mountings and lenses must undergo the same rigorous testing as required for other safety frames and lenses.)

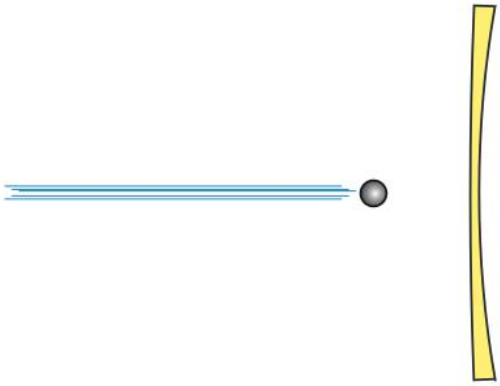

Figure 23.3 In the *high velocity impact test*, a small steel ball is fired at high velocity in order to test a lens or frame.

BOX 23.1 Safety Frame Marking Requirements

Fronts

1. A-dimension (eye size)
2. Distance between lenses (DBL)
3. *Z87* to indicate frame compliance with basic-impact standards or *Z87–2* to indicate frame compliance with high-impact standards (Z87–2 frames may be used for both basic- and high-impact lenses.)
4. Manufacturer's identifying trademark

Temples

1. Overall length
2. *Z87* to indicate frame compliance with basic-impact standards or *Z87–2* to indicate frame compliance with high-impact standards
3. Manufacturer's identifying trademark

Side Shields

Since eye protection is required and used in many occupational and educational settings, eye injuries that happen to people wearing safety glasses often occur from the side.

Side shields may be removable or permanent and are not universally interchangeable. A removable side shield designed for one particular type of frame may not provide the ANSI standard–approved protection required if used on a different type of frame.

Defining Safety Glasses

Safety frames should only be used with safety lenses. Some safety frames may be less expensive than regular dress frames. However, *regular lenses must not be put into a safety frame,* even to save the wearer money. A pair of regular dress lenses placed in a safety frame may give the wearer the impression that they are wearing safety glasses. A safety frame with dress-thickness lenses is no more safety eyewear than a dress frame with safety lenses. Eyeglasses are not safety glasses until both the frame and lenses are in compliance.

Lenses that are made thicker for added safety should not be placed in a pair of regular frames. If safety is important enough to warrant thick lenses, it is important enough to warrant safety or sports-type frames. Safety lenses in regular frames can give the wearer a false sense of security and the mistaken impression that this is a "safe" prescription. *Under no circumstances should a pair of lenses be marked as safety and placed in a non-safety frame.*

Hardening of Glass Lenses

Glass lenses are not strong enough to pass the FDA-mandated impact test unless they are hardened. There are currently two methods of hardening glass lenses. One uses a heat-treating process, and the second uses a chemical-tempering process.

Heat-Treating Process

Heat treating is done by placing the edged glass lens into a small kiln where the temperature is high enough to almost bring the glass to the softening point. The lens is left in the kiln for about 2 or 3 min. The exact amount of time depends upon lens thickness, type of glass, and lens tint.

The lens is removed from the kiln and cooled rapidly by blowing forced air against both front and back surfaces (Figure 23.4).

To understand how this process could cause an increase in impact resistance, remember that as glass heats, it expands and becomes more like a liquid. When the hot lens is struck by cool air against its outer surfaces, the outer surfaces "freeze." The inner part of the lens cools more slowly. As it is cooling, it is trying to contract, but the outer part of the lens is already "frozen" and refuses to shrink further. This creates an inner pull on the lens, inducing stress. Part of the stress is surface

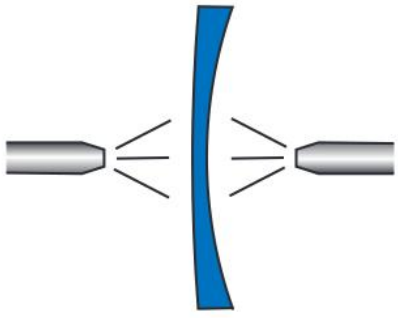

Figure 23.4 When air strikes front and back surfaces of a lens that has been heated just below the softening point, it "freezes" the outside, setting up a controlled internal stress that makes the lens more impact resistant.

compaction or squeezing called *maximum compressive stress*. Another part of the stress is called *maximum tensile stress*. This stress creates strength in the same way that the tightened spokes on a bicycle wheel add strength to the rim. These forces result in a compression of the lens surface. The depth from the outside surface of the lens where compressive stress and tensile stress meet is called the *depth of compression*.

The advantage to heat treating is that it is fast. The disadvantage is that the heat-tempered lens is not as impact resistant as a lens that is chemically tempered.

Chemical Tempering

Glass lenses are chemically hardened by immersing them in molten salt. The salt used for clear crown glass and tinted crown glass lenses is potassium nitrate (KNO_3). During the process of chemical tempering, smaller sodium (Na^+) or lithium (Li^+) ions from the glass are drawn out of the lens surface and replaced by larger potassium (K^+) ions from the salt (Figure 23.5). This crowds the surface, setting up a surface tension that "squeezes" the lens. This surface tension increases impact resistance by creating compressive stresses.

Compared with heat tempering, chemical tempering of crown glass lenses provides superior impact resistance but is a longer process.

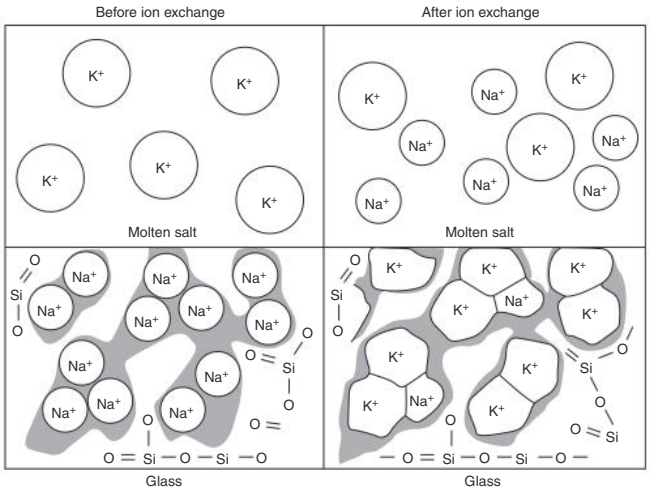

Figure 23.5 In chemtempering, smaller sodium (*Na*$^+$) or lithium (*Li*$^+$) ions from the glass are replaced by larger potassium (*K*$^+$) ions from the molten salt. The glass itself contains silicone (Si) and oxygen (O). Lithium ions do not appear in the diagram. (Krauser RP: Chemtempering today, Corning, NY, 1974, Corning Glass Works.)

Determining Whether a Glass Lens Has Been Hardened

Determining if a lens has been heat treated is possible by viewing it between two crossed polarizing filters. An instrument with a light source and two crossed polarizing filters made for this purpose is called a *colmascope*, or *polariscope*. Viewed through a colmascope, a heat-treated lens will show a Maltese-cross pattern (Figure 23.6). A perfectly shaped Maltese-cross pattern does not mean that the lens is any more impact resistant than a lens showing a misshapen Maltese cross. Rotating the lens while viewing it though the colmascope will cause the Maltese-cross pattern to change in appearance anyway. This pattern shows up because surface compression in a heat-treated lens is nonuniform.[12]

Chemically tempered lenses have an even surface compression and therefore show no stress patterns when viewed through crossed polarizing filters. A chemically tempered lens can only be identified by taking the lens out of the frame and immersing it in a glycerin solution while viewing it between crossed polarizing filters. A chemically hardened lens will show a halolike, bright band around the edge of the lens. Because of the time-consuming inconvenience of this process, everyone depends upon the notification enclosed with the finished spectacle lenses as assurance that the lens has been chemically hardened.

EYE PROTECTION FOR SPORTS

The appropriate selection of eyewear for sports is important. Correct eyewear selection may improve performance in the sport and at the same time protect the wearer.

American Society for Testing and Materials

The American Society for Testing and Materials (ASTM) develops standards for many things, among which are several ASTM standards that apply to eye wear—especially eye wear that is designed to protect the wearer in sports. These are shown in Table 23.4.

The standard for sports that is most often encountered in an eye care practice is the F803 standard. This is called *F803 standard specification for eye protectors for selected sports*. It is especially applicable since it applies to many of the most popular sports such as baseball, basketball, soccer, and tennis.

There is not just one type of protector that provides F803 protection. F803 protection can be in four different types. These are listed in Box 23.2.

Other Cautions with Sports Eyewear

Sports frames are designed to be worn with lenses and should not be worn without them. This is true even if the balls used in a particular sport appear to be too large to get through the frame's lens opening. Small, fast-moving balls may elongate and penetrate the empty lens opening.

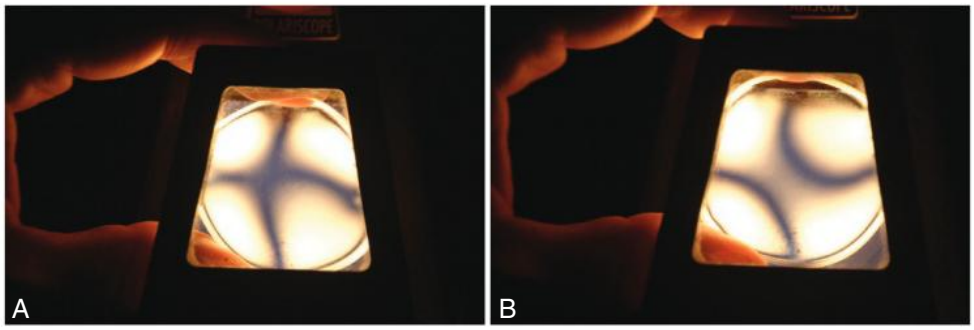

Figure 23.6 **A** and **B,** A heat-treated lens may be identified by the characteristic Maltese-cross pattern seen when the lens is viewed through the crossed polarizing filter of a colmascope. The symmetry of the Maltese-cross pattern is not the important factor. As a lens is rotated, the pattern seen will vary, as seen in **A** and **B** of the same lens seen in two different angles of rotation between the polarizing films.

TABLE 23.4 ASTM Standards Applicable to Sports Eye Protection[13]

Number	Standard Identification Sports Covered by the Standard
ASTM F513	Standard specification for eye and face protective equipment for hockey players
ASTM F659	Standard specification for goggles and face shields protectors for skiers
ASTM F803	Standard specification for eye protectors for selected sports These applicable sports include racquet sports (such as racquetball, badminton, and tennis), women's lacrosse, field hockey, basketball, baseball, and soccer
ASTM F910	Standard specification for face guards for youth baseball
ASTM F1587	Standard specification for head and face protective equipment for ice hockey goaltenders
ASTM F1776	Standard specification for eye protective devices for paintball sports
ASTM F2879	Standard specification for eye protectors used by players of airsoft sports

BOX 23.2 Four Types of F803 Sport Protectors[14]

Type I The front piece is molded as one unit—lens or lenses and front together. However, temples or straps may be separate.
Type II A unit with lens(es) separate from the frame front and then assembled; the lenses are either plano or prescription lenses
Type III A protector without a lens
Type IV A full or partial face shield
Note: If spectacle lenses are worn under protective eyewear, then polycarbonate or Trivex lenses should be worn in the spectacles.

When even a large ball, such as a soccer ball, strikes the eye, the blunt trauma can produce a shock wave impact that causes the eyeball to distort then rebound with a large amount of force, resulting in severe damage. So although a large ball would not seem like it would be able to damage an eye surrounded by the bony structure of the skull, it still can. Sports eyewear protection is still important.

Custom Eyewear Needs for Individual Sports

Each sport has certain unique visual demands. Some demands may be met by simply providing appropriate sunglasses. Others may require a specialized prescription that includes a uniquely positioned multifocal segment. A number of sports and their hazards and problems are listed in Table 23.5, along with recommended solutions. Yet, as with occupational needs, there is not always a single "cookbook answer" for every individual's sports vision needs. Each situation should be discussed and any corrective or protective eyewear designed to meet the needs of that particular individual. However, there are certain common themes that recur in sports eyewear.

Common Themes in Sports Eyewear

Sports eyewear can be confusing because of the large number of sports and sports situations possible. Here are some general statements about sports eyewear that help in getting an overall picture:

- Virtually all sports demand highly impact-resistant lenses made from such materials as polycarbonate or Trivex.
- Helmets are required when there is danger of head injury.
- Outdoor sports call for UV protection, and when intense sunlight is a factor, sun lenses are appropriate.
- Most sports using round balls call for ASTM F803-approved protectors. These include baseball, basketball, soccer, and any racquet sports, such as tennis or badminton.
- Underwater sports for those dependent upon their prescription need special in-mask or in-goggle prescription adaptations.
- Billiards and pistol shooting may require prescription modifications.
- Golf, flying, and shooting may require relocation of multifocal segments and/or optical centers.
- Bicycling and billiards may require changes in the positioning of the frame front.

PROVIDING BEST CHOICES AND PREVENTING LIABILITY

The Dispenser's Obligation in Helping Choose the Most Appropriate Product

The process of dispensing eyewear is one that involves helping the wearer choose the best product for a particular need. This may include absorptive, high-index, aspheric, specialized segmented or progressive lenses, eyewear for certain sports or hobbies, or protective eyewear. Thus, it becomes the responsibility of the dispenser to provide each individual with sufficient information so that an informed decision may be made. It is the dispenser's responsibility to inform the wearer about the availability of eyewear alternatives that provide optimal eye safety in the particular wearing conditions applicable for that individual.

When lawsuits involving eyewear occur, the case is usually made on the basis of either product liability or negligence.[21]

Product Liability

Product liability means that the product was not up to accepted standards. What those standards are depends on the type of eyewear.

- For dress eyewear: Was a drop ball test or batch testing done? (This is the optical laboratory's or manufacturer's responsibility to do. The dispenser should know that it is being done.)
- For safety eyewear: Were Z87 standards met—particularly thickness standards?
- For sports eyewear: Is the design faulty or is there a failure to meet impact resistance expectations? If ASTM standards are appropriate, was eyewear chosen so that those standards were met?

Negligence

To prove negligence, it must be shown that, "the defendant practitioner did not conform to the standard of care expected of like practitioners acting under the same or similar circumstances. Practitioners are expected to exercise reasonable prudence and demonstrate the minimum degree of learning and skill possessed by members of the profession in good standing."[21]

In the case of a dispenser, this would include:

- Failure to recommend the most appropriate material.
- Failure to inform the wearer about decreased impact resistance of other materials compared with the most suitable material.
- Failure to verify that materials received were in accordance with standards required for materials ordered.

TABLE 23.5 Problems, Hazards, and Recommended Solutions for Sports Eyewear

Problems and Hazards	Recommended Solutions
Badminton	
1. Danger from birdie and racquet.	1. Wear ASTM F803-approved sports protectors with polycarbonate lenses.
2. Brightness of outdoor environment.	2. Use sun lenses when appropriate.
Baseball	
1. Hazard of ocular injury from the ball.	1. Batters should wear a batting helmet with attached face shield. Others should wear ASTM F803-approved sports protectors with polycarbonate lenses when playing other positions. Little League players can use a reduced injury factor ball.[15] Youth baseball players should use ASTM F910 standard specification for face guards when appropriate.
2. Brightness of outdoor environment.	2. Wear sun lenses when appropriate. Consider specialized notch filter lenses such as Oakley Prizm Field.
Basketball	
1. Eye hazard from other player's fingers, elbows, etc.	1. Wear ASTM F803-approved basketball protectors with polycarbonate lenses.
Bicycling[16]	
1. Head or eye injury from a fall.	1. Wear a bicycle helmet. Use strong frames with polycarbonate lenses.
2. Dust, sand, or small object blown into the eyes.	2. For both nonprescription and prescription eyewear, wraparound frames and lenses are helpful. Drop in frame fronts may be added, if desired.
3. Ultraviolet (UV) radiation.	3. Add UV protection to lenses (will be included with polycarbonate lenses).
4. Inability to see vehicles from behind without looking backward.	4. Use a special small mirror mounted on the helmet or spectacle frame.
5. Brightness of outdoor environment.	5. Wear sunglasses when appropriate. Consider specialized notch filter lenses such as Oakley Prizm Road or, for trail riding, Oakley Prizm Trail.
6. Bent-over riding position forces eyeglass wearers to look over the top of their frames.	6. Select frames that can be set high on the face. Use adjustable pads, and adjust the glasses high.
Billiards	
1. Viewing the ball on the table must be done through the very tops of the lenses.	1. For conventional frames, choose a frame that is high on the face, has a thin upper rim, and may be adjusted upward. Use a frame specially designed for billiards. Such a frame is thin rimmed, sits high on the face, and has retroscopic tilt.
2. Presbyopia can make the field of view unclear.	2. Prescribe a small amount of additional plus power. Since most viewing is done 1–2 m away, the additional plus required may be as small as +0.25 D but usually not greater than +0.75 D.[17] This can be given in the form of a distance prescription increased in plus by this amount. If bifocals are used in this same lens, the bifocal segment should be low set and the add power decreased in plus by an equal amount to compensate for the increased plus found in the distance.
Boating/Fishing	
1. Glare from the water.	1. Use a polarizing lens, which also blocks UV light. Consider specialized notch filter lenses such as Oakley Prizm Shallow Water Polarized or Oakley Prizm Deep Water Polarized. If a photochromic lens is desired, use Transitions XTRActive polarized. (Remember, however, that these do not polarize light from behind a windshield.)
2. There is intensified UV radiation from both overhead and reflected UV light.	2. Use a sunglass lens that cuts out all UV light below 400 nm. Wear with a brim or a visor.
3. Glasses that drop from the face or are knocked off will sink and be lost.	3. Use a well-fitting frame, possibly one that has cable temples. Consider using an athletic strap when boating. Some have used eyeglass floats that attach to the temples or to a strap attached to the temples behind the head.

TABLE 23.5 Problems, Hazards, and Recommended Solutions for Sports Eyewear—cont'd

Problems and Hazards	Recommended Solutions
Flying	
1. Overhead dials and gauges are difficult to read with a normal presbyopic correction.	1. Inform the pilot of the existence of occupational double-segment lenses. However, many presbyopia pilots prefer progressive addition lenses. Progressive addition lenses are a good choice because of the various distances at which near gauges and dials must be viewed.
2. Bright daylight flying reduces dark adaptation at night.	2. Use sunglasses with frames that are large and have short vertex distances or that wrap around. Select lenses that do not transmit more than 15% of the light. Do not use polarizing lenses.
Football[15]	
1. Eye injury from the ball or other players.	1. Wear an approved helmet with face guard or cage. Additional protection is possible using eye protection, such as Liberty's Helmet Specs, which are designed to be worn under the helmet and behind the guard or cage.
Golf	
1. Bifocals and other normal presbyopic corrections may interfere with viewing the ball during swing.	1. Use single-vision lenses. Tradition says to use one small round bifocal segment only: for right-handed players, on right, for left-handed players, on left. Position the segment either in the extreme upper temporal corner or the extreme lower temporal corner. It is best to mark the glazed lenses with a colored marking pen where the segment will be positioned. Have the wearer use a golf club and simulate the playing situation ahead of time. This solution is often talked about but seldom used.
2. Frame interferes with vision.	2. Use thin-rimmed, rimless, or nylon cord frames. Avoid frames with thick, wide temples.
3. UV exposure.	3. Wear a hat with a brim or visor. Add UV protection to lenses.
4. Brightness of outdoor environment.	4. Wear sun lenses when appropriate, but know that many golfers say that polarizing lenses will decrease their ability to read the contour of the course. Consider specialized notch filter lenses such as Oakley Prizm Golf or Oakley Prizm Dark Golf.
Handball	
1. Danger from ball.	1. Always use ASTM F803-approved sports eye protectors with polycarbonate lenses.
Hockey: Ice[15]	
1. Danger from pucks and sticks.	1. Use helmet with full-face wire or polycarbonate face protector approved by the ASTM F513 standard for Eye and Face Protective Equipment for Hockey Players or by the Canadian Standards Association. Avoid half shields and form-fitting goalie masks.
Hockey: Street, Floor, or Field[15]	
1. Danger from pucks and sticks.	1. Use helmet with full-face wire or polycarbonate face protector approved by the ASTM F513 standard for Eye and Face Protective Equipment for Hockey Players or by the Canadian Standards Association. Use ASTM F803-approved eye protectors with polycarbonate lenses.
Lacrosse: Women's	
1. Danger from ball and players' sticks.	1. Use ASTM F803-approved eye protectors with polycarbonate lenses intended for women's lacrosse.
2. Brightness of outdoor environment.	2. Wear polycarbonate sun lenses in conjunction with protective eyewear when appropriate.

Continued

TABLE 23.5 Problems, Hazards, and Recommended Solutions for Sports Eyewear—cont'd

Problems and Hazards	Recommended Solutions
Motorcycling	
1. Head and/or eye injury from a fall.	1. Wear a motorcycle helmet with face shield. If helmets are not used, vented goggles should be. Venting is to prevent fogging.
2. Dust, sand, or small objects blown into the eyes.	2. Use strong frames and polycarbonate lenses. Wraparound frames and lenses are helpful.
3. UV radiation.	3. Add UV protection to glasses (will be included with polycarbonate lenses).
4. Brightness of outdoor environment.	4. Wear sun lenses when appropriate. Polarizing sunglasses reduce road glare.
Mountain Climbing	
1. Increased exposure to UV radiation because of less atmospheric absorption.	1. Use UV-absorbing goggles that eliminate all wavelengths below 400 nm.
2. Brightness of outdoor environment.	2. For high altitudes in which brightness is especially excessive, use sun lenses with approximately 5% transmission and a wraparound design or use sunglasses with side shields (often leather).[17]
Paintball	
1. Danger of paintball injury to eyes.	1. Wear ASTM F1776 eye protective devices for paintball sports.
Racquetball	
1. Danger from ball and opponent's racquet.	1. Always use ASTM F803-approved eye protectors with polycarbonate lenses intended for racquetball.
Horseback Riding[15]	
1. When riding in other than open areas: brush or twigs.	1. Use polycarbonate lenses. (Riding helmets should conform to ASTM standards, but they do not include eye protection.)
2. UV exposure.	2. If dress eyewear is worn for riding, polycarbonate lenses should be chosen.
3. Brightness of outdoor environment.	3. Wear sun lenses when appropriate.
Running	
1. Sweating, causing slipping eyeglasses.	1. Use a sweatband. Use comfort cable temples or an eyeglass headband. For low prescription powers, try simply not wearing eyeglasses.
2. Fogging up eyeglasses.	2. Be certain that the frames do not ride on the cheeks. Consider an antifogging lens treatment.
3. UV exposure.	3. Wear a hat with a brim or visor. Add UV protection to glasses, or wear sunglasses with UV protection.
4. Outdoor brightness.	4. Wear sunglasses or polarized sunglasses. Consider specialized notch filter lenses such as Oakley Prizm Road or Oakley Prizm Trail.
Shooting: Pistol[18]	
1. Danger of reverse discharge of powder.	1. Use polycarbonate lenses.
2. Need for large field of view.	2. Use large (even 62-mm A dimension and larger) metal aviator frames.
3. Need for improved contrast and/or reduced glare.	3. Traditional shooter preference for overcast days is an amber tint. This is not a recommendation, since there is no proven correlation between shooting performance and an amber tint, although many shooters use these or orange tints. Each shooting situation should be evaluated and judgment made on individual need using the principles outlined in Chapter 22.
4. Pistol shooting has a unique need for focusing on the pistol sights rather than on the target. This can be troublesome for presbyopes.	4. Early presbyopes should consider using a specifically designed device that is mounted to spectacle frames. It consists of a diaphragm mounted before the dominant eye and an occluder mounted before the nondominant eye. As an alternative, punch a 1- to 2-mm hole through a piece of electrical tape using a 1/32-inch nail. Mount the tape with pinhole directly in the line of sight.

TABLE 23.5 Problems, Hazards, and Recommended Solutions for Sports Eyewear—cont'd

Problems and Hazards	Recommended Solutions
	Late presbyopes should use an add power prescribed for the distance from the spectacle plane to the pistol sights. For accuracy, it is more important for the sight to be in focus than the target. That add may be fit as: a. Near viewing distance single-vision glasses. b. A bifocal mounted very high on the sighting eye (in a shooting stance the sight is seen through the bifocal and the upper part of the target is viewed through the distance lens). c. An add lens is mounted in the flip-up portion of a double-front frame. The nondominant eye usually has an occluder in the flip-up portion.
Shooting: Rifle[18]	
1. Danger of reverse discharge of powder.	1. Use polycarbonate lenses.
2. Blurring of the front sight of the rifle (some presbyopes are bothered by this problem).	2. Convert to a telescopic sight for which no accommodation is required.
3. Need for improved contrast or reduced glare.	3. See Shooting: Pistol.
4. The dominant eye does not correspond to the dominant hand, making sighting with the dominant eye impossible.	4. Specially designed gun stocks are available.
Shooting: Shotgun[18]	
1. Danger of reverse discharge of powder.	1. Use polycarbonate lenses.
2. Stock jolts against frame.	2. Do not fit frame too low. Choose a frame with a flat lower edge.
3. Need for improved contrast or reduced glare.	3. See Shooting: Pistol.
4. During aiming, the line of sight passes through the upper nasal part of the lens and, for lenses with high distance powers, causes a prismatic effect that may create problems. Some progressive addition lenses may be problematic when viewing through this upper nasal section of the lens.	4. Use contact lenses or, if spectacles are used, mark the location of the line of sight on the spectacle lens and have the laboratory place the optical center of the lens at this location. (To prevent binocular problems, the optical center of the other lens must be moved to the same vertical position and outward temporally to achieve the correct binocular distance.) If progressive addition lenses are to be worn, avoid using softer design progressive addition lenses that allow asphericity to flow into the upper peripheral areas of the lens.
Skiing	
1. Exposure to UV radiation resulting in "snow blindness" (burning and photophobia from photokeratitis).	1. Use lenses that eliminate all wavelengths below 400 nm.
2. Wind and flying snow.	2. Wear ASTM F659-approved ski goggles. Some are designed to hold prescription lenses. Some have double lenses to reduce fogging.
3. Blurring from bifocal or trifocal segments for presbyopes.	3. Use a single-vision lens. To reduce fogging, consider a lens with antifogging qualities.
4. Brightness of outdoor environment.	4. Protective sun lenses are appropriate. It may be helpful to avoid polarizing lenses. Some skiers believe that it hinders judgment of snow conditions. Also, as the body tilts, the polarizing lenses will vary in their absorption of horizontally polarized light. Consider specialized notch filter lenses such as Oakley Prizm Snow.
Snorkeling and Scuba Diving[19]	
1. Eyeglass prescription needed to see clearly.	1a. Use a removable mask insert. The insert is like a "frame front" that attaches to the front surface of the mask. 1b. Cement lenses to inside of mask as follows: With the mask in place, mark the front of the mask as if taking monocular interpupillary distances as described in Chapter 3. Calculate the correct lens power for the vertex distance from the eye to the face mask surface (see Chapter 14). Order lenses for the corrected distance prescription with plano front base curves. (Minus lenses work well, but plus lenses have problems because, with plano front curves, they would essentially be worn backward.) Cement the lenses to the inside of the mask with clear epoxy or UV curing cement.

Continued

TABLE 23.5 Problems, Hazards, and Recommended Solutions for Sports Eyewear—cont'd

Problems and Hazards	Recommended Solutions
2. The inside of the mask fogs up.	2. Use a mask that has been antifog treated or use an antifogging lens cleaner. (Note: Some antifogging agents may evaporate into the mask chamber and cause eye irritation or even corneal erosion.[20] If agents are used, they should be allowed to dry thoroughly before wearing the mask or goggles.)
3. Presbyopes encounter difficulty seeing near objects clearly.	3. Use a specially designed multilens or bifocal mask. The multilens mask has distance and near prescription in the mask, whereas the bifocal mask has only near lenses in the lower half. As an alternative, bond a near add lens to the lower left-hand side of the mask.
Soccer	
1. Danger from ball or collisions with other players.	1. Use ASTM F803-approved protective eyewear with polycarbonate lenses for soccer.
Squash	
1. Danger from ball and opponent's racquet.	1. Always use the appropriate ASTM F803-approved eye protectors.
Swimming	
1. Water gets in the eyes and water changes the refractive power of normal spectacles, making underwater wear of normal spectacles unproductive.	1. Use swimming goggles. Goggles may be fit with powered lenses. Base curves of lenses in contact with water must be plano to retain the intended power characteristics both above and below the water. Order goggles with interchangeable, premanufactured, refractive power (spherical equivalents). Contact lenses may be worn underneath plano goggles.
2. Swim goggles fog up.	2. Use a goggle with back-surface antifogging properties. (See also under *Snorkeling and Scuba Diving* above.)
Tennis	
1. Danger from ball and racquet.	1. Use the appropriate ASTM F803-approved eye protectors with polycarbonate lenses.
2. Brightness of outdoor environment.	2. Wear polycarbonate sun lenses when appropriate.
Volleyball	
1. Being hit with the ball.	1. Use ASTM F803-approved protective eyewear with polycarbonate lenses.
2. When played outdoors, bright sunlight and reflections from sand or water can be a hindrance and a hazard from UV exposure.	2. Use polycarbonate sun lenses with UV protection in an appropriate F803 protector.
Water Skiing	
1. Water spray gets in eyes.	1. Use a goggle similar to a swim goggle but with holes in the sides to prevent fogging. Use swimming goggles and drill 3/16- to ¼-inch holes temporally in the sides.
Wrestling	
1. Eye protection currently not conducive to the sport.	1. Monocular individuals or individuals with good correctable acuity in one eye only should avoid wrestling.[15]

Note: When polycarbonate material is listed, it should be noted that Trivex is also highly impact resistant and may also be suitable.

Responsibility for Recommending the Most Appropriate Lens Material

One of the most important decisions an eyeglass wearer will make relates to the safety of the product. According to Classé,[21,22] there are five general classes of persons for whom safety is of great importance. These are the following:

1. Monocular individuals (An individual should be considered as "monocular" if the weaker eye has a corrected visual acuity of less than 20/40.)
2. Athletes
3. Children
4. People with occupations that put them at risk for ocular injury
5. Individuals whose eyes have a reduced capacity to withstand ocular trauma, including aphakes and pseudophakes, high myopes, those who have undergone refractive surgery, and those who have had previous eye injuries

It is the dispenser's responsibility to identify these individuals, make them aware of their need for eye protection, and recommend the most impact-resistant lens material available. In some cases, this will involve recommending a certain type of frame as well.

Whether or not the practitioner deems the prospective lens wearer in need of high-impact–resistant lenses, each person should be informed of the availability of the safest lens product. The person can then make a personal decision on the matter.

Suppose a person is not informed of the availability of the safest lens product and subsequently has a severe eye injury. In such a case it is easy for the wearer to say, "If I had been told about this lens, I would have chosen it, and this would never have happened to me."

In instances in which a person has an eye examination but requires no refractive correction, the examiner who takes a thorough case history will note the need for protective eyewear. If protective eyewear is needed, that need is not limited to full-time eyeglass wearers. The need for safety or sports eyewear includes the need for plano safety or sports eyewear.

If a prescriber strongly believes that a certain lens material should be used for a given eyewear function, then that material should be written on the prescription, making it required.

To prevent liability, everyone purchasing eyewear should be informed of the safest lens products. It is advisable that this should also be documented in the health record.

Responsibility for Recommending Safety or Sports Frames

If eyeglasses are to be worn for contact sports or for activities hazardous to eyes, wearers need to know about options available. If these options are not brought to the wearer's attention, the wearer may assume that his or her "dress wear" frames and lenses will provide all the protection needed.

The following are some situations that may require safety or sports eyewear[23]:

- Working with lawn or garden equipment, such as string trimmers, shredders, or chain saws
- Working with shop equipment, such as power saws, drills, or grinders
- Working with hazardous liquids, such as acids or alkalis, or with sprayers
- Engaging in contact sports or sports using balls or racquets

It should be obvious that any time a safety frame is needed, an impact-rated lens is also necessary.

Any lens or frame safety information explained to the wearer should be noted in the record and dated, as should the wearer's final selection of lens material and frame.

Responsibility to Inspect the Finished Product

When newly fabricated spectacles are returned from the laboratory, it is the dispenser's responsibility to inspect the finished product. If the lens is classified as a safety or sports product, it must comply with all the requirements outlined by ANSI or ASTM standards.

If an eye injury occurs, expect that all these factors will be checked for the injured by their legal counsel. If any ANSI or ASTM standards are unmet, it is obvious that either (a) an inspection was never done or (b) that inspection was done incompetently or inadequately.

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PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. True or false? A coating on a plastic lens will change the impact resistance of that lens compared with its uncoated state.
   a. True
   b. False
2. What is the name of the instrument used to check to see if a glass lens has been heat treated?
   a. alphascope
   b. betascope
   c. colmascope
   d. deltascope
3. For lenses of equal powers and thicknesses, which lens material shows greater impact resistance when tested using a small, high-velocity projectile?
   a. an untreated crown glass lens
   b. a chemically tempered crown glass lens
   c. a chemically tempered photochromic lens
   d. a CR-39 lens
4. For lenses of equal power and thickness, which lens material shows greater impact resistance when tested using a large, slow-moving object like a softball?
   a. an untreated crown glass lens
   b. a chemically tempered crown glass lens
   c. a CR-39 lens
5. Given the following plano-powered lenses, which will be the most impact resistant?
   a. a 3-mm thick photochromic, chemically hardened glass lens
   b. a 2-mm thick polycarbonate lens
   c. a 3-mm thick heat-treated crown glass lens
   d. a 3-mm thick CR-39 lens
6. Which lens does not have to be *individually* drop-ball tested?
   a. a −5.00 D single-vision crown glass lens
   b. a +2.50 D single-vision polycarbonate lens
7. True or false? Rimless frames may not be used for safety eyewear.
   a. True
   b. False
8. True or false? Listing a lens material as part of an eyeglass prescription is inappropriate.
   a. True
   b. False
9. True or false? Because the laboratory takes full responsibility for the accuracy of safety and sports prescription eyewear, verification of lens thickness by the dispenser is unnecessary.
   a. True
   b. False
10. The correct ophthalmic terminology for eyewear that is used for everyday wear and not for sports or safety is
    a. casual eyewear.
    b. everyday eyewear.
    c. formal eyewear.
    d. dress eyewear.
    e. standard eyewear.
11. What are the minimum thickness requirements mandated by the FDA for dress eyewear?
    a. 1.0 mm
    b. 1.5 mm
    c. 2.0 mm
    d. 2.2 mm
    e. There are no minimum thickness requirements.
12. When may retailers dispense prescription lenses that are not impact resistant?
    a. when the wearer signs a waiver accepting responsibility
    b. when no other types of impact-resistant lenses will fulfill the visual requirements of the wearer
    c. both of the above
    d. neither of the above
13. What is the standard "referee test" for determining impact resistance suitable for dress ophthalmic lenses?
    a. a 1-inch steel ball dropped on the front surface of the lens from a height of 50 inches.
    b. a 1-inch steel ball dropped on the front surface of the lens from a height of 52 inches.
    c. a 5/8-inch steel ball dropped on the front surface of the lens from a height of 50 inches.
    d. a 5/8-inch steel ball dropped on the front surface of the lens from a height of 52 inches.
    e. a 1/4-inch steel ball shot at the front of the lens at a speed of 150 ft/s
14. True or false? Plano sunglasses manufactured in quantity do not have to be impact resistant.
    a. True
    b. False
15. Which lens is most likely to break?
    a. an unscratched lens
    b. a lens that has been scratched on the front surface
    c. a lens that has been scratched on the back surface
    d. All lenses are equally likely to break.
16. What are the minimum thickness requirements for *nonimpact-rated* safety eyewear?
    a. 2.0 mm
    b. 2.2 mm
    c. 3.0 mm (except for +3.00 D or higher in power, which have a minimum thickness of 2.5 mm)
    d. 3.2 mm (except for +3.00 D or higher in power, which have a minimum thickness of 2.8 mm)
    e. 3.2 mm (except for +3.00 D or higher in power, which have a minimum thickness of 2.5 mm)
17. What are *impact-rated* safety eyewear minimum thicknesses?
    a. 2.0 mm
    b. 2.2 mm
    c. 3.0 mm (except +3.00 D or higher in power, which have a minimum thickness of 2.5 mm)
    d. 3.2 mm (except +3.00 D or higher in power, which have a minimum thickness of 2.8 mm)
    e. 3.2 mm (except +3.00 D or higher in power, which have a minimum thickness of 2.5 mm)
18. What is the standard "referee test" for determining impact resistance suitable for *nonimpact-rated* prescription safety lenses?
    a. a 1-inch steel ball dropped on the front surface of the lens from a height of 50 inches
    b. a 1-inch steel ball dropped on the front surface of the lens from a height of 52 inches
    c. a 5/8-inch steel ball dropped on the front surface of the lens from a height of 50 inches
    d. a 5/8-inch steel ball dropped on the front surface of the lens from a height of 52 inches
    e. a 1/4-inch steel ball shot at the front of lens at a speed of 150 ft/s

19. How must a safety frame suitable for safety lenses be marked on the front and temples?
    a. With size and manufacturer
    b. With size, manufacturer, and Z87+
    c. With size, manufacturer, and Z87–2
20. True or false? Putting 2.0-mm thick CR-39 lenses in a safety frame but not marking the lenses for safety is acceptable if the person just wants the glasses for regular wear.
    a. True
    b. False
21. True or false? Putting 2.0-mm thick polycarbonate lenses in a safety frame but not marking the lenses for safety is acceptable if the person just wants the glasses for regular wear.
    a. True
    b. False
22. True or false? A glass lens may be identified as having been chemically tempered by placing it in a colmascope. (A colmascope consists of two crossed polarizing filters that are back lighted.)
    a. True
    b. False
23. In order for prescription swim goggles to satisfy vision requirements above and below the water, the lenses
    a. must be a multifocal
    b. must be high index material
    c. must be AR coated
    d. must be fit at a 14- mm vertex distance
    e. must have a plano base curve
24. Which sport may require a prescription modification for the type of sports eyewear used?
    a. hockey
    b. lacrosse
    c. bicycling
    d. billiards
    e. badminton
25. True or false? The ASTM sports eyewear standard for racquetball is the same standard as the one for basketball.
    a. True
    b. False
26. True or false? A large ball such as a soccer ball is unlikely to harm the eye if struck. The bony structure around the eye serves to protect the eye.
    a. True
    b. False

24

How Lenses Are Edged

SPOTTING OF SINGLE-VISION LENSES WITHOUT PRISM

First, a lens is made ready for edging so that the refractive power and optical centration will be correct. For edging, we should always be starting with a lens of a known power.

Power Verification and Spotting of Spheres

When the power of the lens to be verified is of known power, set the lensmeter for the expected sphere value. If the lens is a sphere, the target should be immediately clear, indicating a lens of the correct power.

Optically, center the lens in the lensmeter by moving the lens until the center of the illuminated target crosses the center of the crosshairs in the lensmeter eyepiece or screen (Figure 24.1) The marking device is then swung into position, and the front surface of the lens is spotted.

Power Verification and Spotting of Spherocylinders

When verifying spherocylinder lenses, the lensmeter power wheel is turned to the expected sphere power. The cylinder axis wheel is also turned to the axis of the prescription. The lens-holding device is not allowed to touch the lens, and the lens is rotated until the sphere lines of the lensmeter target are sharp and unbroken. When these lines are clear, the cylinder axis is correct.

With the lens correctly rotated for axis position, turn the lensmeter power wheel in the appropriate direction for checking the cylinder power.

Next, carefully move the lens left, right, upward, or downward until the target is accurately centered. (Remember to pull the lens-holding device away from the lens surface so that the lens will not get scratched.) When the target is accurately centered, the lens may be spotted.

The power verification in a spotting procedure for spherocylinder lenses is summarized in Box 24.1.

Marking the Lens for Right or Left

As soon as the lens is spotted, it should be removed from the lensmeter and marked for the right or left eye. Lenses are marked on the *front* surface with a wax pencil. The letter *R* or *L* in uppercase letters is written in the upper half of the lens above the three spots (see Figure 24.2). Because it is written on the front but viewed from the back so that it may be clearly seen after the lens has a lens block on the front, the *L* or *R* is written in reverse.

SPOTTING OF SINGLE-VISION LENSES WITH PRISM

The Optical Center of a Lens

When there is no prescribed prism in the prescription, the needed point of reference is the optical center (OC). The OC becomes the reference point. It is of major importance in aligning the lens. Therefore, it is known as the *major reference point* (*MRP*). So, *when there is no prism in the prescription, the OC* ***is*** *the MRP.*

When the Optical Center Is Not in the Line of Sight

Sometimes a prescription includes prescribed prism. The lens must be positioned so that the desired amount of prism is placed in front of the wearer's pupil in the eye's line of sight. When prism is included in the prescription, the point on the lens with the correct amount of prism becomes the point of reference. *When the prescription contains prescribed prism, the OC and MRP are two separate points.*

There is a synonym for the MRP that is perhaps even more descriptive. That synonym is "*prism reference point*" or PRP. MRP and PRP are the same.

The procedure of spotting single-vision lenses with prism is nearly identical to that of nonprism lenses. The only difference is in how the illuminated target is centered. Instead of placing the center of the illuminated target at the center of the crosshairs, the center of the illuminated sphere and cylinder target lines must be positioned to correspond to the location of the desired prismatic effect.

Example 24.1

A right lens calls for 2.0Δ base-out prism. How would it be positioned for spotting?

Solution

To correctly position this lens:

- The center of the sphere and cylinder target intersection must be on the circular mire marked 2.0.
- Because the prism is horizontal, the illuminated target must be on the 180-degree line.
- Base out for the right eye is to the operator's left. Therefore the center of the illuminated target must be on the 2Δ prism circle where it crosses the 180-degree line to the left.

When the lens is correctly positioned, the lensmeter target appears as shown in Figure 24.3.

Once this position is achieved and the cylinder axis is correct, the lens may be spotted. Figure 24.4 shows the lens spotted with the three lensmeter dots. The center lensmeter ink spot is no longer at the center of the unedged lens, but the center dot still indicates the location of the MRP.

When Prescribed Prism Includes Both Horizontal and Vertical Components

In a case in which both horizontal and vertical prisms are called for simultaneously in the same lens, the target must be moved both laterally and vertically until it reaches the desired position prior to spotting. That position is one in which the target center is directly above (or below) the required horizontal prism reading. It is also exactly left or right of the required vertical prism reading.

Example 24.2

A right eye requires 4.0Δ base out and 2.0Δ base up. How would the lens be positioned for spotting?

Solution

To correctly position the lens, the target must be four full prism diopter units to the left of center *and* two full prism diopter units above center. This is shown in Figure 24.5.

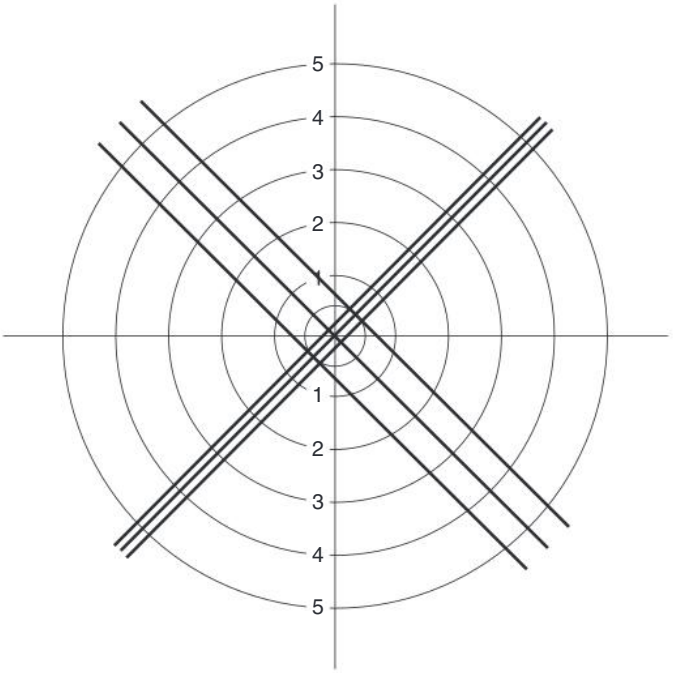


Figure 24.1 When both sphere and cylinder lines focus at the same time, the lens has a uniform power in all meridians and is spoken of as being spherical.

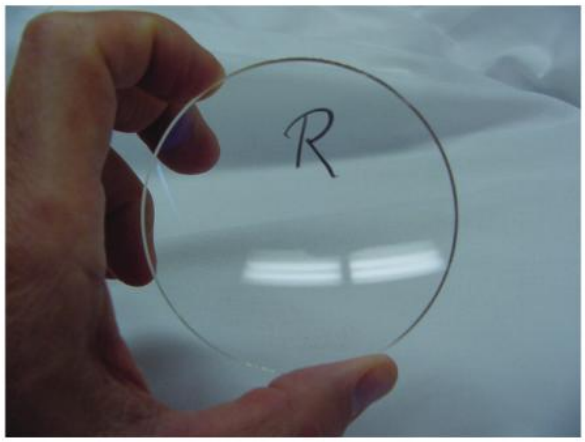


Figure 24.2 The lens designation (*R* or *L*) is always marked on the upper half of the lens so that the lens will not be blocked upside down. An inverted prism or an upside down multifocal lens would be worse than useless. (The lens is being viewed from the back side.)

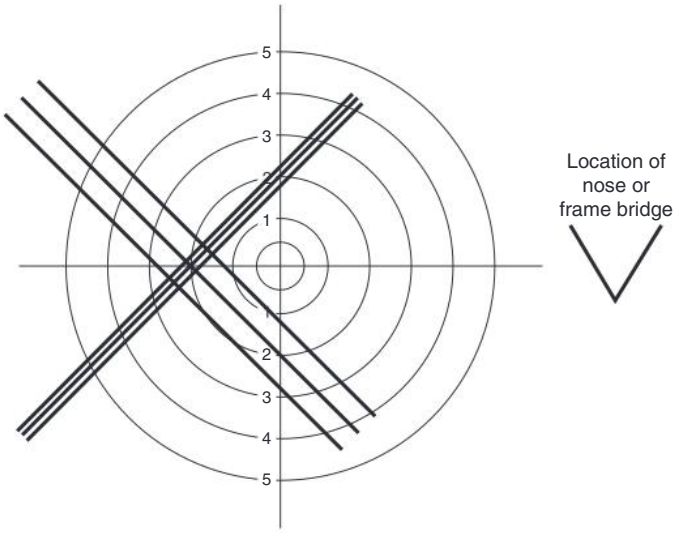


Figure 24.3 Prismatic effect can be created by decentering the lens in the lensmeter until the sphere and/or cylinder line intersection is positioned for the indicated amount. (Achievement of desired prism by decentration is limited by lens size and refractive power.)

BOX 24.1 How to Spot Single-Vision Sphere or Spherocylinder Lenses Using a Standard Crossed-Line–Target Lensmeter

1. Dial in the lens sphere power and lens cylinder axis into the lensmeter.
2. Place the lens in the lensmeter.
3. Locate the major reference point.
4. If the lens is spherical, spot the lens.
5. If the lens has a cylinder, rotate the lens until the sphere lines are clear.
6. If the lens has prescribed prism, move the illuminated target until it is located at the position where the prism equals that called for in the prescription.
7. Spot the lens.

SPOTTING OF FLAT-TOP MULTIFOCAL LENSES

For segmented multifocal lenses, the bifocal should be placed in the lensmeter like it will be when mounted in the frame. This means that for flat-top bifocal lenses, the segment top should be horizontal. The sphere power is dialed into the lensmeter. If the lens has a cylinder component, the axis of the cylinder should be dialed in as well.

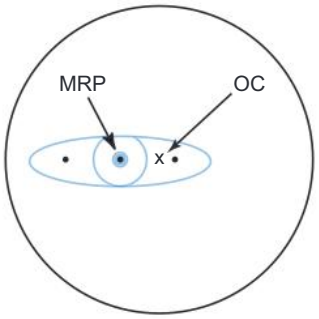


Figure 24.4 The major reference point (*MRP*) of a lens will ultimately be positioned before the wearer's pupil center. If prism is indicated in the prescription, the optical center (*OC*) is displaced purposely. Therefore the point that will be important in centration and is consequently spotted is the MRP, not the OC.

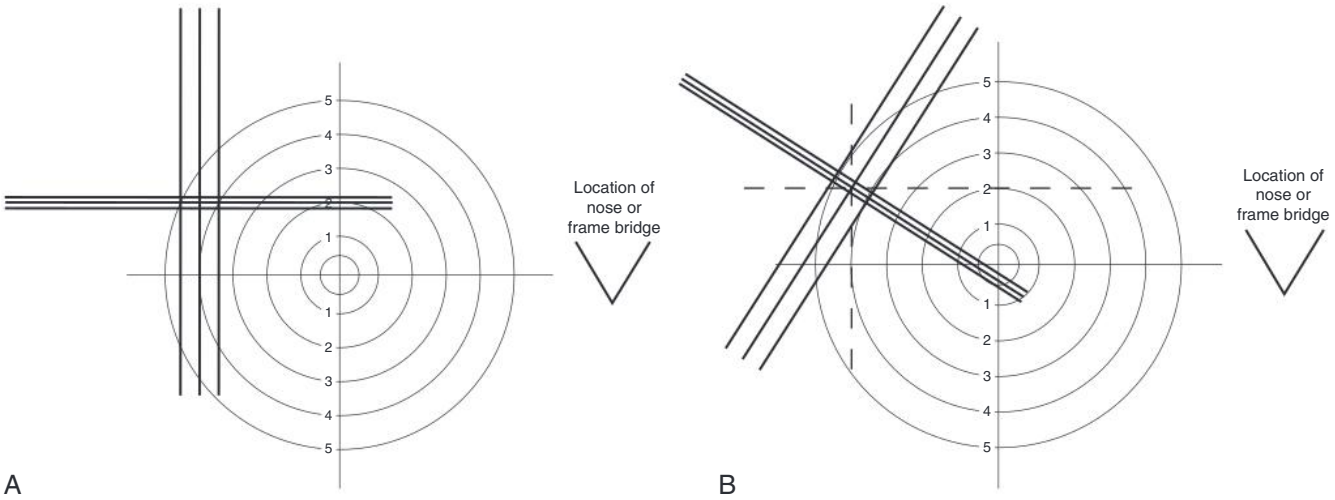


Figure 24.5 In positioning a prismatic lens, the only important reference is the center of the illuminated target. This is the place where the center sphere and cylinder lines cross each other. Where other parts of those lines may cross the circular mires is of no importance. In the example shown, the sphere and cylinder line crossing point must be directly above or below the place where the 4.0Δ circle crosses the horizontal line farthest from the "nose." The sphere and cylinder line crossing point must simultaneously also be exactly at the same level as the top of the 2.0Δ circle. **A,** This is easy to see because the sphere and cylinder lines are aligned horizontally and vertically. However, if there is cylinder present at any axis other than 90 or 180, the lines will not look like this. Instead they may appear as shown in **B**. The prismatic effect shown in **B** is exactly the same as in **A**. Both are 4Δ base out and 2Δ base up. It may be difficult to tell the exact position of the center of the illuminated target for a spherocylinder lens with an oblique axis. If you have difficulty, try this procedure. Temporarily turn the cylinder axis to 90 or 180 degrees. This will cause the illuminated target lines to be exactly horizontal and vertical. Now, although the lines will be a bit blurred, they will duplicate the situation shown in **A** and make it easier to tell how much vertical and horizontal prism is present.

Next the MRP of the lens is located. When the lens is spherical, the lens may be spotted.

For multifocal lenses with spherocylinder powers, the axis of the cylinder has been custom ground for that particular lens. The lensmeter is set for the axis ordered and the lens rotated to the correct axis. With MRP and cylinder axis correct, the lens is spotted, just like a single-vision lens. After the lens has been spotted, the three dots on the 180-degree line should be parallel to the upper edge of a flat-top segment (Figure 24.6, *A*). If they are not parallel to the top of the bifocal segment, the cylinder axis is off and the lens was surfaced improperly.

To precheck the lenses as a pair, hold the lenses front to front with the segments overlapping (see Figure 24.6, *C*). If the center spots of both lenses are not at the same place, there is likely to be a problem with unwanted horizontal or vertical prism after the lenses are edged. Exceptions to equal overlap will be in cases of (1) unequal monocular PDs, (2) unequal segment heights, or (3) unequal MRP heights.

For a summary of spotting flat-top multifocal lenses, see Box 24.2.

SPOTTING PROGRESSIVE ADDITION LENSES

Progressive addition lenses have certain semivisible markings used in establishing lens orientation. Lenses coming from the surfacing laboratory are also marked with non-water–soluble ink. If the visibly inked marks are correctly applied, there is no need to spot the lenses. However, the accuracy of where the inked locations are should be verified before the lenses are edged.

Verifying Premarked Progressive Lenses

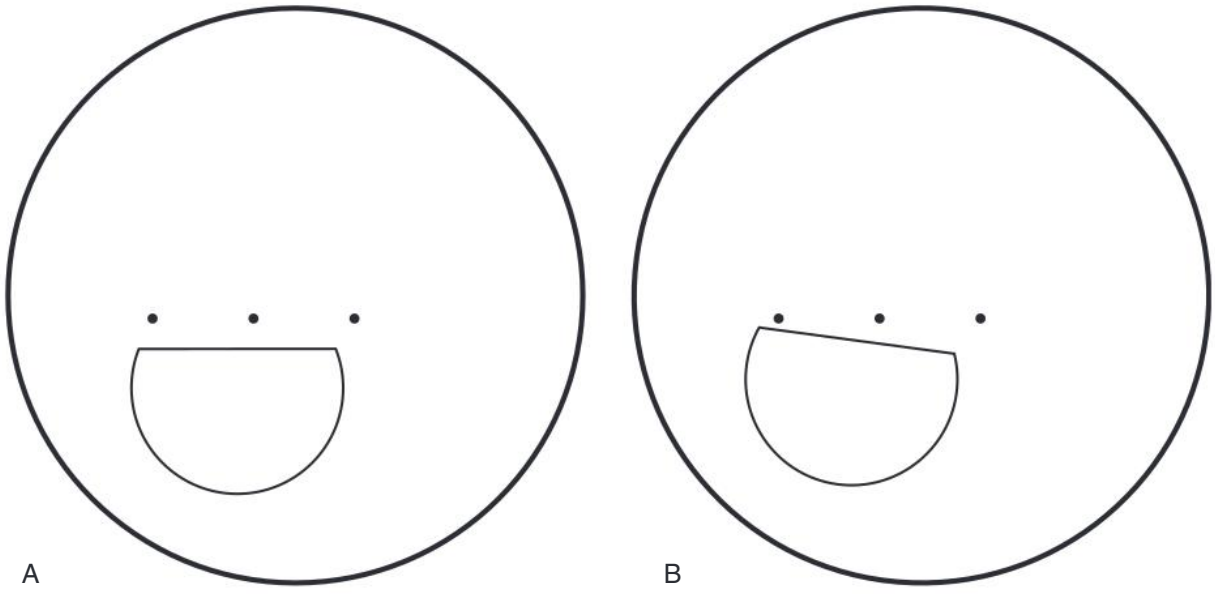
To check distance lens power, position the lens in the lensmeter to view through the circle or arc above the PRP. (The PRP usually comes marked with a dot.) This circled, or arced, area that is used to locate the point for verifying distance power is called the *distance reference point*, or *DRP* (Figure 24.7). Incidentally, remember that there will almost always be some prism at the DRP since the DRP of the lens is not the optical center (OC) of the lens.

To check distance power, set the power wheel to the sphere power and the cylinder axis wheel to the ordered cylinder axis. Rotate the lens until the target lines are clear and unbroken. The non-water–soluble horizontal reference marks on the lens should be horizontally oriented and not tilted. If they are tilted, the axis of the cylinder is incorrect.

To check for prism, the lens is centered in the lensmeter at the PRP. (Remember, the PRP is the same as the MRP.)

Progressive lenses often come with equal amounts of vertical prism in both right and left lenses. This allows the lenses to be made thinner. Equal amounts of "yoked" vertical prism for "prism thinning" purposes are both allowable and usually expected. For example, both right and left lenses may read 1.5Δ base down at the PRP and are still considered free of unwanted vertical prism.

As stated earlier, if the lenses are correct and have non-water–soluble progressive lens markings, there is no need to spot the lens. The existing progressive lens markings will be used to align the lens for edging. If the lenses do not come with markings or if it appears that the markings were inaccurately applied, then the markings must be reapplied.



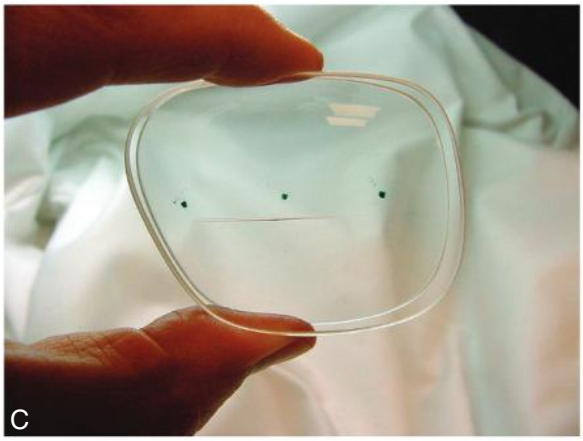


Figure 24.6 **A,** For spherocylinder lenses, the three dots should be parallel to the top of the segment. If they are not, the cylinder axis will be wrong. **B,** For spherical lenses, an angle between the three dots and the segment top is not a problem, even though it looks off. However, if the lens has a cylinder component, the axis of the cylinder will be wrong. (To avoid alignment confusion, if the lens is a sphere it may be helpful to wipe the two outer lensmeter dots off of the lens.) **C,** Once flat-top bifocal lenses have been spotted, they may be prechecked before edging. Hold the edged lenses front to front. They are held front to front because the segments and spots are closer to one another and will reduce the amount of parallax seen. Do not press the lenses into contact with one another to prevent scratching. Make sure the segments exactly overlap each other. With both lenses having equal seg insets and drops, the spots should also overlap as shown. If they do not overlap, there may be a problem with PD being off or there may be unwanted vertical prism.

BOX 24.2 Spotting Flat-Top Multifocal Lenses

1. Dial the lens sphere power and lens cylinder axis into the lensmeter.
2. Place the lens in the lensmeter.
3. Locate the major reference point.
4. If the lens is spherical, spot the lens.
5. If the lens has a cylinder, rotate the lens until the sphere lines are clear.
6. If the lens has prescribed prism, move the illuminated target until it is located at the position where the prism equals that called for in the prescription.
7. Spot the lens.
8. For spherocylinder lenses and lenses with prescribed prism, verify that the segment top and three lensmeter dots are parallel to one another.
9. When both lenses have been spotted, line up the lenses front to front to check for R-L spotting accuracy. The central spots should overlap unless unequal heights or insets have been ordered.

When Progressive Lenses Are Not Premarked

In the event that a progressive addition lens has no visible markings, reconstruct them using the manufacturer's recommended system of identifying marks and a lens template. This procedure was explained in Chapter 20.

PATTERNS

Pattern Measurements and Terminology

To allow the edger to shape the lens to fit the frame, a pattern is needed. That pattern can be a physical pattern made of plastic or, more commonly, an electronic pattern stored in the memory of a computer. Here are some specifics on pattern measurement and terminology.

The *mechanical center* of a pattern is the point on the pattern around which the pattern rotates. The mechanical center is easy to find since it is located in the middle of the large hole in the pattern (Figure 24.8).

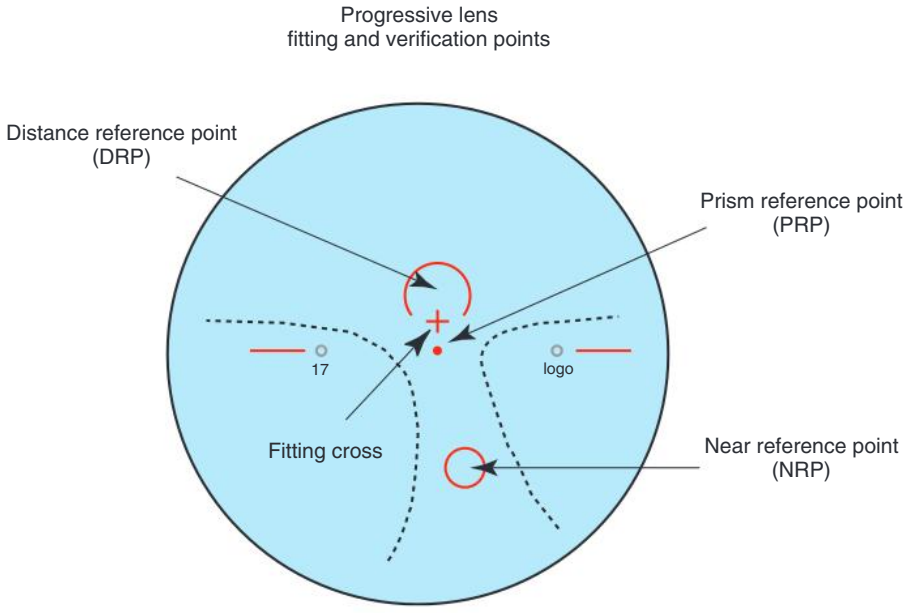


Figure 24.7 Points of reference on a progressive addition lens.

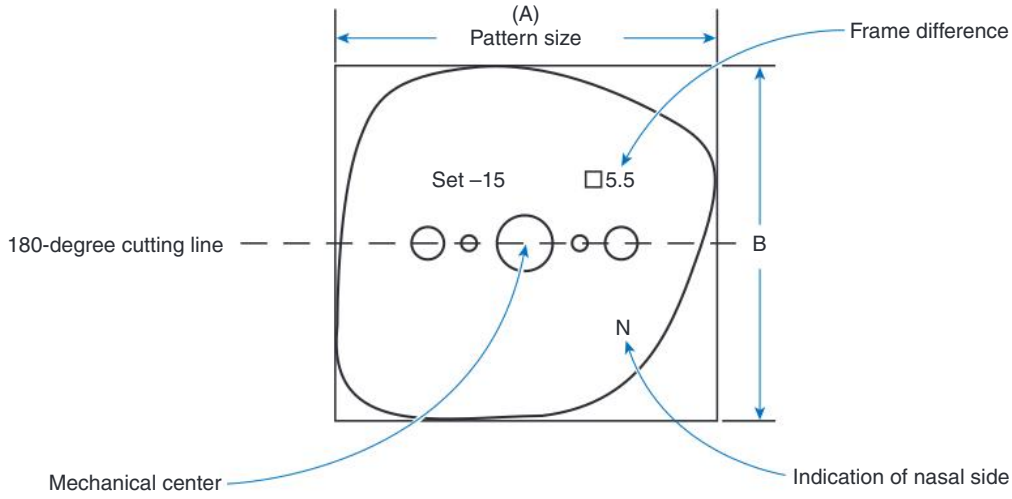


Figure 24.8 The same system of measurement that is used for frames and lenses is also used for patterns. Patterns do not come with A and B dimensions marked, but they do have a pattern set number to help in finding the correct edger setting. The "frame difference" helps in positioning the major reference point and multifocal heights when the laboratory does not have the frame.

Centration and Decentration

The process of moving a lens so that it will be in front of the eye is called *centration*. To center the lens in front of the eye, the lens must be moved *away* from a given reference point. When a lens is moved away from a given point, it is said to be *decentered* from that point. In this case, the lens is moved away from, or *decentered,* from the location of the mechanical and boxing centers.

Pattern Making

Because of the vast number of available frame styles, it is impossible to have a complete library of patterns so that the correct pattern is available for every frame presented for lens fabrication. Ordering a pattern for every single frame that passes through the laboratory is totally impractical. The delays caused would not be acceptable to the wearer, not to mention the volume of paperwork that would be generated. For this reason, when running an edger that uses patterns, a system for making patterns is a necessity.

How the Pattern Is Placed on the Edger

By convention most people begin the edging process with the right eye. When the pattern is snapped into place on the edger, it will fit on the edger with either the front or the back of the pattern going on first. Going on one way will edge a right lens shape, whereas the other way will produce a left lens shape.

USING A FRAME TRACER FOR PATTERNLESS SYSTEMS OF EDGING

Patternless edgers that do not use a physical pattern still need a shape to go by. This shape is given to the edger in digital form. To get a digital

version of the shape, that shape must sooner or later be physically traced and transferred to the edger digitally.

A pattern shape is generated by using a frame tracer. A *frame tracer* is an apparatus that traces the shape of the frame's lens area and converts it into digital form.

A Frame Tracer Can Be Used in a Variety of Locations

A Tracer Can Be Situated Right Next to the Edger

When a tracer is situated right next to the edger, the person doing the edging has immediate access to the frame.

A Tracer Can Be a Part of the Edger

A tracer that is part of the edger has the advantage of requiring less working space.

A Tracer May Be Placed in the Order Entry Area of a Laboratory

When the tracer is placed in the order entry area of the laboratory, information is only entered once.

A Tracer May Be Placed in a Remote-Site Dispensary

One of the biggest headaches for dispensers is the situation in which a wearer wants to keep his or her old frame but cannot or will not give it up long enough to send it to the laboratory. If there is a frame tracer on site, the dispenser can remove the lenses, trace the shape, reinsert the lenses, and give the spectacles back to the wearer (Figure 24.9).

The information is then sent to the laboratory electronically. It is entered into the computer system just as if it had been entered in the laboratory order entry area.

When the dispensary uses a frame tracer to send information, the laboratory can get a head start on any lenses before the new frame arrives. In the interest of time, the dispensary may choose to not send the new frame at all and insert the lenses themselves.

(***Warning!*** A frame tracer can be fraught with problems having to do with tracer calibration, errors in operation, and unnoticed flexing of the frame during tracing, resulting in a distortion in edged-lens shape. These can be harder to overcome when the tracer is being used remotely.)

Tracers Can Transfer Data to a Surfacing Laboratory

For the surfacing laboratory to grind a lens to the optimum thickness, the laboratory needs accurate data. This is especially true for plus lenses. The size and shape the lens will have when edged is essential for calculating plus lens thickness. The more exact the data, the more precisely the thickness can be controlled. If the lens is traced, those tracing values may be sent to more places than just the edger. Values can be sent to a computer program for lens surfacing that calculates both lens curves and thickness as well as controls the surfacing equipment.

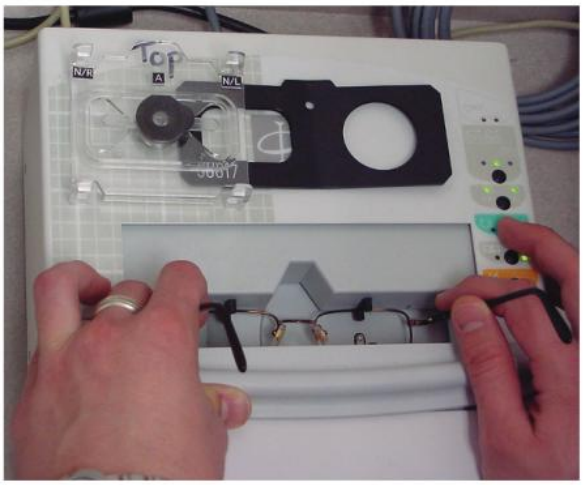


Figure 24.9 A frame tracer may be used at a remote, off-site location. This ensures that the frame dimensions as read at the dispensary are exactly what will be input into the edger.

CENTRATION OF LENSES

Centration of Single-Vision Lenses

During the edging process, the lens rotates while being ground to a specific shape to fit the frame. This point of rotation corresponds to a hole in the pattern. If one pattern is to be used for a number of different pairs of glasses, this hole should be in the middle of the pattern used on the edger (unless the pattern is a custom-made pattern that includes a wearer-specific decentration). This middle point, the *geometric* or *boxing center* of the lens, is defined as being the center of the smallest rectangle that encloses the lens shape using horizontal and vertical lines.

For the MRP of the lens to be centered before the wearer's pupil, the lens must be moved, or *decentered*, away from the boxing center of the lens.

Distance Between Centers

For frames that conform to the boxing system of measurement, the distance between centers (DBC) (also called the *frame PD*) is equal to the eye size (abbreviated A) plus the *distance between lenses* (DBL).

$$\text{DBC} = \text{A} + \text{DBL}$$

Decentration Per Lens

Most commonly, the wearer's PD will be less than the DBC. This will require that the lenses be decentered inward (nasally) toward the center of the frame. The amount of decentration per lens can be determined by subtracting the wearer's PD from the DBC and dividing by 2.

$$\frac{\text{DBC} - \text{Wearer PD}}{2} = \text{Decentration per lens}$$

Example 24.3

A wearer's PD is 62 mm. The frame size has an A dimension of 48 mm and a DBL of 20 mm. What is the decentration per lens required?

Solution

To find decentration per lens, we use the formula

$$\text{Decentration per lens} = \frac{\text{DBC} - \text{PD}}{2}$$

and since

$$\text{DBC} = \text{A} + \text{DBL}$$

$$\text{Decentration per lens} = \frac{\text{A} + \text{DBL} - \text{PD}}{2}$$

Then

$$\text{Decentration per lens} = \frac{48 + 20 - 62}{2}$$

$$= \frac{68 - 62}{2}$$

$$= \frac{6}{2}$$

$$= 3 \text{ mm}$$

So, for the example, the decentration needed per lens is 3 mm inward.

Determining Decentration From Monocular PDs

When a prescription specifies the wearer's PD in reference to each eye individually, PDs are taken one eye at a time. This measurement is referred to as the *monocular PD*. For a monocular PD, the reference is basically from the center of the bridge of the nose to the center of the pupil. For example, if we have a more conventionally measured *binocular PD* of 64, we may have a right monocular PD of 31 and a left monocular PD of 33. This difference between left and right PDs is not unusual considering the asymmetry of facial features of many normal individuals.

For a monocular PD, decentration is determined by *first* dividing the distance between centers (DBC) of the frame by 2, *then* subtracting the monocular PD; thus

$$\text{Decentration} = \frac{\text{DBC}}{2} - \text{Monocular PD}$$

or

$$\text{Decentration} = \frac{\text{A} + \text{DBL}}{2} - \text{Monocular PD}$$

How to Calculate Vertical Centration

MRP height is the distance from the lower line of the box enclosing the shape of the lens up to the MRP location. The laboratory must convert from MRP height to MRP raise (or drop).

Example 24.4

An order specifies an MRP height of 25 mm. The frame has a vertical dimension (B) of 46 mm. What will the MRP raise be?

Solution

Vertical decentration is calculated as

$$\text{Vertical decentration} = \text{MRP height} - \frac{\text{B}}{2}$$

In the example, since MRP height is 25 mm and the frame B is 46 mm, then

$$\begin{aligned}\text{Vertical decentration} &= 25 - \frac{46}{2}\\ &= 25 - 23\\ &= 2\text{ mm}\end{aligned}$$

It can be seen that since the MRP height is greater than half of the B dimension, the vertical decentration is positive, and the lens is moved up by 2 mm. The height above (or below) the horizontal midline of the lens may be visualized from Figure 24.10.

Steps in Centration of Single-Vision Lenses

Following are the steps in using a centration instrument for single-vision lenses:

Step 1: Spot the lens (as described earlier).

Step 2: Assuming the instrument has blocking capabilities, stick a double-sided adhesive blocking pad on a lens block, and mount the block on the instrument. Then, peel the paper off the pad to expose the adhesive.

Step 3: Calculate the amount of horizontal decentration per lens required using the formula:

$$\text{Decentration per lens} = \frac{\text{A} + \text{DBL} - \text{PD}}{2}$$

Step 4: Determine if the lens must be decentered to the right or to the left. In most centering devices, the lens will be face up. If the lens is a right lens and is facing up, decentration "in" is to the right. A left lens facing up would be decentered to the left.

Step 5: Adjust the position of the movable vertical reference line in the instrument to the right or left by the amount of decentration calculated.

Step 6: Next, place the right lens face up (front surface up) on the screen. Align the three spots on the lens with the horizontal line on the instrument screen.

Step 7: Place the center lens dot on the movable vertical reference line. (Remember, the position of this line corresponds to horizontal decentration.)

Step 8: When the MRP height is specified, decenter the lens up (or in rare instances, down). The amount of decentration is according to the correct number of millimeters of MRP raise (or drop).

Step 9: Grasp the handle and swing it into place or press the button or foot switch to block the lens.

Example 24.5

A frame has an eye size (A) of 54 mm and a DBL of 20 mm. The wearer's PD is 66 mm. The lenses are already spotted. How must the instrument be set and the lens placed to properly block the lens? Assume that the lens is a *left* lens.

Solution

Lens decentration is calculated as

$$\begin{aligned}\text{Decentration per lens} &= \frac{\text{A} + \text{DBL} - \text{PD}}{2}\\ &= \frac{54 + 20 - 66}{2}\\ &= \frac{8}{2}\\ &= 4\text{ mm}\end{aligned}$$

To preset the movable vertical line in the instrument for the left lens, first recall in which direction the MRP should be moved. Because the wearer's PD is smaller than the frame's geometric center distance (A + DBL) or frame PD, the lenses will be decentered nasally, or inward. The lens is placed convex side up. Therefore the left lens is moved to the left so the movable vertical line is positioned 4 mm to the left of the central reference line.

With the lens face up in the instrument, align it such that the central dot is at the intersection of the horizontal line and the movable vertical line as shown in Figure 24.11. The other two dots must fall directly on the horizontal reference line.

Block the lens. The location of the center of the lens block will become the boxing center of the edged lens (Figure 24.12).

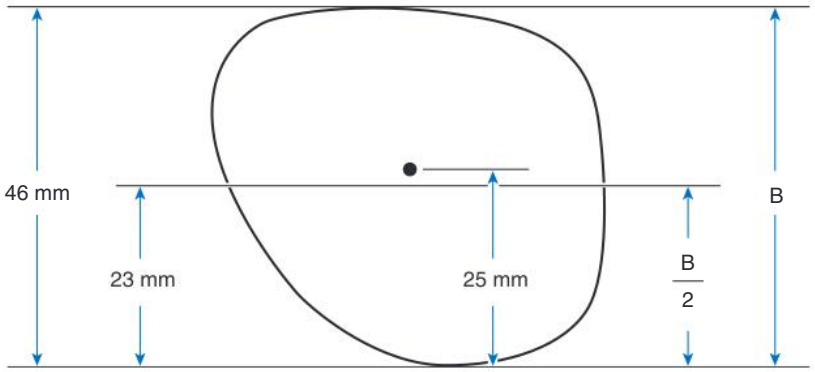


Figure 24.10 If the position of the MRP is given in terms of height from the lowermost portion of the shape, drop or raise can be calculated by subtracting one-half the B dimension from MRP height.

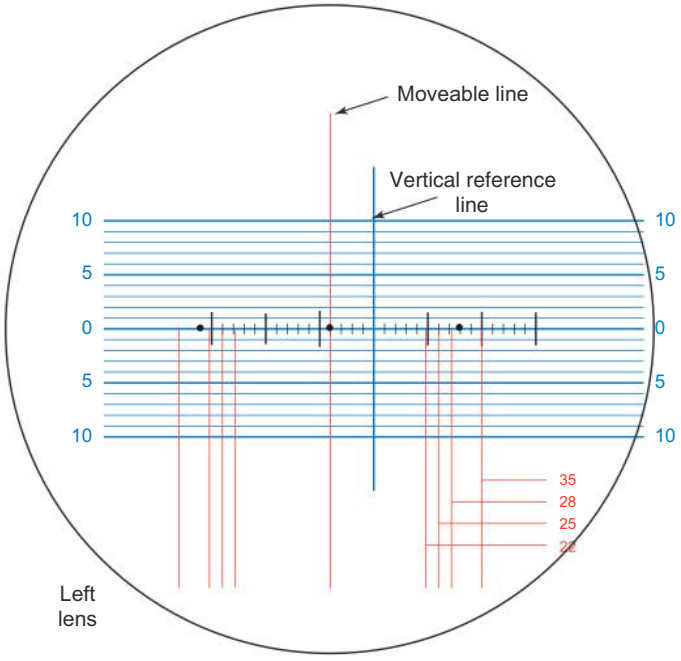


Figure 24.11 The movable line is preset to the correct decentration. The movable line helps to prevent the dot on the lens from getting "lost" on the grid. With the movable line pointing out the desired MRP (major reference point) location, the lens is positioned as shown.

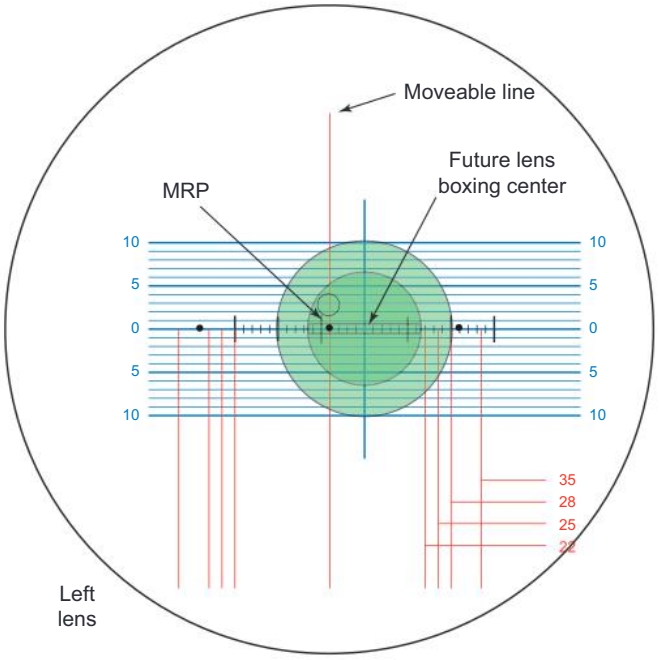


Figure 24.12 On the centration device, the block is always placed at the origin. The block center corresponds to the *future* geometric or boxing center, of the *edged* lens.

Centration of Progressive Lenses

The fitting cross is to be positioned exactly in front of the wearer's pupil and comes visibly marked on the lens. It is the only reference point for both horizontal and vertical lens positioning for the dispenser. It is also the primary reference point for both horizontal and vertical lens positioning for the edging laboratory.

In simplest terms, centration of a progressive addition lens is done as if the lens was a single-vision lens. For single-vision lenses, the MRP is placed at the correct monocular or binocular PD, depending upon how it is ordered. For a progressive lens, the fitting cross is placed at the correct monocular PD.

For a single-vision lens, the MRP is placed on the horizontal midline of the lens or at the specified MRP height if one is ordered. For a progressive lens, the fitting cross is placed at the specified fitting cross height.

Example 24.6

A progressive addition lens is ordered as follows:

R: + 3.00 − 1.00 × 070
L: + 3.00 − 1.00 × 110
Add: + 1.50 D

Monocular PDs are

R: 33 mm
L: 31 mm

Vertical fitting cross heights are

R: 25 mm
L: 23 mm

Frame dimensions are A = 50, B = 40, DBL = 20

Answer these questions.

1. How much horizontal decentration per lens is required?
2. How much fitting cross raise or drop per lens is needed?
3. How will the right lens appear on a centration device when correctly centered for blocking?

Solution

1. For a progressive lens, the horizontal decentration for a monocular PD is calculated in the same way as it is for a single-vision lens. So, in this example problem

$$\text{Decentration} = \frac{(\text{A} + \text{DBL})}{2} - \text{Monocular PD}$$
$$= \frac{(50 + 20)}{2} - 33$$
$$= 2\ \text{mm}$$

Therefore, horizontal decentration for the right lens is 2 mm.

Horizontal decentration for the left lens is

$$\text{Decentration} = \frac{(\text{A} + \text{DBL})}{2} - \text{Monocular PD}$$
$$= \frac{(50 + 20)}{2} - 31$$
$$= 4\ \text{mm}$$

2. For the right lens, the fitting cross raise or drop above or below the horizontal midline is calculated as follows:

$$\text{Raise or drop} = \text{Fitting cross height} - \frac{\text{B}}{2}$$
$$= 25 - \frac{40}{2}$$
$$= 25 - 20$$
$$= +5\ \text{mm}$$

Therefore, the fitting cross raise for the right lens is 5 mm.

For the left lens, the fitting cross height is

$$\text{Raise or drop} = \text{Fitting cross height} - \frac{\text{B}}{2}$$
$$= 23 - \frac{40}{2}$$
$$= 23 - 20$$
$$= +3\ \text{mm}$$

Therefore, the fitting cross raise for the left lens is 3 mm.

3. The lens is positioned in the centration device using the fitting cross for reference.

For a summary of how progressive addition lenses are positioned for edging, see Box 24.3.

Centration of Segmented Multifocal Lenses

The near-viewing segment area in conventional multifocal lenses has a clearly demarcated line that borders the segment. This can be used as a stable, convenient reference when positioning the lens for blocking.

The vertical location of the segment is measured for each wearer. The dispenser gives this vertical location in terms of segment height. This segment height must be converted to segment raise or drop.

The dispenser gives the horizontal location of the segment in terms of the wearer's distance and near PDs. This must be converted to segment inset relative to the boxing center of the edged lens.

The centration of standard flat-top bifocal lenses is done as follows:

1. Verify the lens for power and MRP location. Spot the location of the MRP with the lensmeter.
2. Place the lens block in the instrument.
3. Determine the total seg inset required.

$$\text{Total inset} = \frac{(\text{A} + \text{DBL}) - \text{Near PD}}{2}$$

4. Determine if the lens must be decentered to the right or to the left. If the lens is convex side up, for a right lens, decenter to the right; for a left lens, decenter to the left.
5. Position the movable vertical line in the instrument to the right or left by the amount of decentration calculated.
6. Calculate the amount of seg drop or raise required.

$$\text{Seg drop} = \text{Seg height} - \frac{\text{B}}{2}$$

7. Place the lens face up in the instrument, and align the segment between the segment border lines.
8. Move the lens up or down so that the segment top is at the seg drop or raise called for.
9. Grasp the handle of the instrument and swing it into place or press the button or foot switch to block the lens.

EDGING THE LENS

Edgers that require a physical pattern to guide the edger are often referred to as *patterned edgers.*

However, the template to produce a lens shape does not have to be something tangible, such as a plastic pattern. It can be a shape that is

BOX 24.3 Steps in the Centration of Progressive Addition Lenses

1. Find the location of the semivisible reference circles on the front surface of the lens, and dot the centers of these two circles.
2. Place the lens on the manufacturer's lens blank chart. The dots must be on the indicated circle locations. Verify the accuracy of the lens markings—especially the location of the fitting cross. If they are wrong, remove the old markings and redraw the marks on the lens.
3. Verify the lens by checking distance power at the DRP (distance reference point), prism power at the PRP (prism reference point), and near power at the NRP (near reference point).
4. Calculate distance decentration per lens using monocular PDs.
5. Calculate fitting cross raise or drop.
6. Preset the movable line in the centration device for the distance decentration.
7. Place the lens face up in the centration device, and position the fitting cross on the movable line.
8. Move the lens up until the fitting cross is at the fitting cross height.
9. Verify that the 180-degree markings on the lens are parallel to the horizontal lines in the centration device.
10. Block the lens for edging.

stored digitally. That electronic version can also guide the lens edger. Because this type of an edger works without a physical pattern, it is referred to as a *patternless edger*. Most all edgers now sold will be patternless.

Edging With Patterns

Setting the Edger Size

If all lens patterns were exactly the same size as the required finished lens, then no size setting would be required. However, this would mean that instead of having one pattern for each frame shape, a separate pattern would be required for every available size.

This raises the question of pattern size. The "standard size" was set at 36.5 mm.

To Prevent Pattern Distortion, the Pattern Is Made Larger

When a lens is edged to a shape that is 2 mm larger than the size of the pattern, the edger makes the lens a millimeter larger in every direction—nasally, temporally, upward, and downward. However, in adding an equal amount of lens size to the original shape in every direction, the integrity of the original shape starts to be lost. To keep the shape from being distorted, the only feasible solution was to produce a pattern for larger style frames that was closer in size to the actual lens size being edged.

If the pattern is made larger than the standard 36.5-mm size without size compensation, the lens will be edged larger than the frame's eye size.

Example 24.7

A pattern is supplied for a certain frame. This pattern measures 46.5 in its A dimension. Suppose the lens is to be edged for a 50-mm eye size. If the edger is calibrated for a pattern size standard of 36.5 mm, what size lens will be edged if the edger sizing dial is set for 50 mm?

Solution

For this edger, a 36.5-mm pattern will produce the lens size at which the edger sizing dial is set. If a 50-mm lens is desired, the dial is set at 50 mm. However, since the pattern is 10 mm too large, the lens produced will also be 10 mm too large. Setting the edger at 50 mm in conjunction with this pattern will produce a lens having a 60-mm eye size.

Example 24.8

In Example 24.7, what would the edger setting have to be to produce a 50-mm lens?

Solution

That pattern is 46.5 mm. This is 10 mm larger than the standard and will produce lenses 10 mm too large. Therefore, 10 mm must be subtracted from the required eye size.

$$50\,\text{mm} - 10\,\text{mm} = 40\,\text{mm}$$

To arrive at a 50-mm lens, the edger must be set for 40 mm.

Set Numbers

To make it easier to know how to compensate for a pattern that is larger than the 36.5-mm standard pattern size, frame manufacturers put a compensation number on the pattern. This compensating number is called the *set number*. Because patterns are almost always larger than the standard, this difference must be subtracted from the eye size. For this reason, set numbers are seen as negative numbers.

Patterns that are made for a manufacturer's frame have a set number stamped directly on the pattern. Knowing the eye size and pattern set number means the edger setting can be done without having to measure the pattern. (Because manual, patterned edgers are in the minority, do not expect frame manufacturers to supply patterns.)

Example 24.9

A lens is to be edged for a frame having an A dimension of 53 mm. The pattern is stamped "set-15." What is the proper edger setting?

Solution

"Set-15" means that we need to set the edger 15 mm less than the desired lens size. Therefore, to find the edger setting, we use

$$\text{Edger setting} = \text{Eye size} + (\text{Set number})$$

In this case that will be

$$\text{Edger setting} = 53 + (-15)$$
$$= 38\,\text{mm}$$

So the edger is set for 38 mm.

What if the Pattern is the Same Size as the Frame's Eye Size? When an edger is calibrated for a standard size pattern whose A dimension is 36.5 mm, setting the edger at 36.5 mm will always produce a lens that is exactly the same size as the pattern. So if a pattern is made directly from a frame and duplicates the frame's eye size, then a 36.5-mm setting will give the correct lens size.

Some Automated Patternless Edgers Do Decentration Calculations

Automated patternless edgers reduce the need for calculating edger setting numbers. This is because the digital "pattern" and the needed lens size are the same. Some edgers go further. Calculating lens decentration is not difficult, but, like any simple arithmetic computation, it is easy to make a simple mistake.

It is not difficult for a patternless edger to do the decentration. When tracing both right and left lenses, the tracer also knows the distance between lenses. The only thing that is unknown is the wearer's PD. If the edger asks for the wearer's PD, decentration can be easily given.

Some edgers do both calculations and decentration. Even if the edger figures decentration, the person blocking the lens still has to first decenter and then block the lens.

Some patternless edgers are made to work with the blocker or have a blocker built into the edger. If there is a direct interface between the blocker and the edger, the lens does not have to be decentered nasally by the operator. The operator just positions the spotted lens so that the OC (or MRP) is in the middle of the blocker grid as if there were no decentration at all. Then one of two things happens:

1. the blocker moves the lens block over to where it would normally be positioned or
2. the lens is blocked right in the middle, and the edger takes that factor into consideration when it is edging the lens.

PROFICIENCY TEST

(Answers can be found in the back of the book.)

1. Which type of lens has one power over the entire lens?
   a. a single-vision lens
   b. a segmented multifocal lens
   c. a progressive addition lens
2. A "frame tracer" sends information to:
   a. a lensmeter.
   b. a lens blocker.
   c. a lens edger.
3. Arrange the steps in the edging process in their correct order.
   1. blocking
   2. centration
   3. edging
   4. finding lens axis and MRP location
   a. 2, 3, 1, 4
   b. 2, 4, 1, 3
   c. 1, 2, 3, 4
   d. 4, 2, 1, 3
   e. 4, 3, 2, 1
4. When spotting a single-vision lens for edging in reference to *edged lens orientation,* the lensmeter ink dots will be on
   a. the sphere meridian.
   b. the cylinder meridian.
   c. the 180-degree meridian.
   d. the cylinder axis.
5. Which point should *always* appear either exactly in front of (or somewhat below) the wearer's pupil?
   a. OC
   b. DBC
   c. Geometric center
   d. MRP
   e. DBL
6. If there is no prescribed prism in the prescription, all of these points except one are the same. Which one is ***not*** the same?
   a. OC
   b. MRP
   c. PRP
   d. NRP
7. For which of the following prescriptions is there a difference in the physical location of the OC and the MRP?
   a. −4.00 D sphere
   b. −4.00 − 2.00 × 180
   c. −4.00 D sphere with 0.5Δ base-in prism
   d. *OC* and *MRP* are synonymous terms, hence they are always at the same point on a lens.
8. A flat-top bifocal lens is spotted for the MRP and it is immediately evident that the three dots are *not* parallel to the segment line. In which lens prescription is this of no consequence?
   a. It is always of consequence.
   b. −1.00 − 1.00 × 180
   c. pl −1.00 × 070
   d. −2.25 D sphere
   e. −2.25 D sphere 1.5Δ base out
9. Horizontal and vertical prismatic effect for a progressive addition lens is verified at the
   a. NRP.
   b. PRP.
   c. DRP.
10. True or false? Horizontal pattern size is measured horizontally through the central hole in the pattern.
    a. True
    b. False
11. A lens is to be edged for a frame with an A dimension equal to 48 mm and a DBL of 18 mm. If the wearer has a PD of 60 mm, what is the decentration per lens?
    a. 6 mm
    b. 5 mm
    c. 4 mm
    d. 3 mm
    e. 2 mm
12. What is the DBC for a frame with the following dimensions?
    A = 47
    B = 39
    DBL = 20
    ED = 48
    a. 59 mm
    b. 67 mm
    c. 68 mm
    d. Not enough information is given.
13. How much decentration per lens is required to correctly position these lenses for edging?
    R: +1.00 − 1.00 × 070
    L: −1.00 − 1.00 × 100
    A = 52
    B = 49
    DBL = 16
    PD = 70
    a. 1 mm in
    b. 1 mm out
    c. 1.5 mm in
    d. 2.0 mm in
    e. None of the above is correct.

14. How much decentration is required for the right lens for the frame and monocular PD given for the right lens?
A = 52
B = 43
ED = 54
DBL = 18
R monocular PD = 32
L monocular PD = 33
a. 1.5 mm outward
b. 2 mm inward
c. 2.5 mm inward
d. 3 mm inward
e. 4 mm inward

15. A wearer's PD is 68, the frame A = 48, the DBL is 18, and the B dimension is 40 mm. The order specifies an MRP height of 23 mm for both lenses. How much vertical decentration is needed?
a. no vertical decentration
b. 1 mm down
c. 1 mm up
d. 3 mm down
e. 3 mm up

16. A pattern is marked "set-15" and the frame has an eyesize of 62. For what setting should a manual edger be set?
a. 62
b. 52
c. 47
d. 36.5

APPENDIX

ANSI Z80.1 Prescription Ophthalmic Lenses—Recommendations

Before using the standards outlined in this section, one thing should be made clear. Unlike the American National Standards Institute standards for safety eyewear (ANSI Z87.1) that have been adopted by the Occupational Safety and Health Administration (OSHA), standards for dress prescription eyewear are not requirements, but recommendations. They are voluntary.

The Z80 Committee also encourages members of the eye care community to take into account how capable the devices used in measurement are when attempting to apply the standards to specific prescription ophthalmic lenses.*

The information summarized here in tabular form is not meant to be all-inclusive. For complete information, consult the original document. This is *Z80.1-2020 American National Standard for Ophthalmic—Prescription Ophthalmic Lenses—Recommendations.* This standard may be obtained from:

The Vision Council
Z80 Secretariat
225 Reinekers Lane
Suite 700
Alexandria, VA 22314

INTRODUCTION

How the Standard Is Applied to Compensated Powers

The ANSI Z80.1 standard applies to the prescription as written *unless* the laboratory makes compensations to that prescription in order to retain the intent of the prescription.

For example, when lenses are placed in a frame that has a large amount of "wraparound," tilting the lens around the 90-degree meridian to more closely form to the face, there will be unwanted sphere and cylinder power induced. The manufacturer may recalculate the prescription to counteract this effect of lens tilt. When this is done, the manufacturer lists new sphere, cylinder, and axis values. *When this is the case, then these standards are applied to the recalculated compensated values and not to the originally ordered prescription.* In other words, the ordering eye care practice applies ANSI Z80.1 standards to the numbers the laboratory has provided and not to the original prescription numbers sent to the laboratory with the order.

The Standard Assumes the Minus Cylinder Form of Prescription Writing

When referring to the sphere power of a lens prescription, that could mean two different things, depending upon whether the prescription is written in the plus cylinder or minus cylinder form of prescription writing. In the presence of a cylinder component, each form of prescription writing gives a different value for the sphere power, even though both forms yield the same outcome. The ANSI standard assumes that the prescription being verified is written in the minus cylinder form of prescription writing. Therefore, if the prescription being verified is in plus cylinder form, it should first be transposed to the minus cylinder form before verification standards are applied (Tables A.1 to A.11).

TABLE A.1 Distance Refractive Power Tolerances for Single-Vision Lenses and Segmented Multifocal Lenses

	Sphere Power (When Written in Minus Cylinder Form)	Tolerance for Sphere Power	TOLERANCE FOR CYLINDER POWERS OF: ≥0.00 D ≤2.00 D	>2.00 D ≤4.50 D	>4.50 D
For Single-Vision and Segmented Multifocals **NOTE:** This also applies to some occupational progressive lenses, which would include degressive power lenses (near variable focus lenses) and assistive power lenses (low add progressive lenses).	From 0.00 up to ±6.50 D	±0.13 D	±0.13 D	±0.15 D	±4%
	Powers greater than ±6.50 D	±2%	±0.13 D	±0.15 D	±4%

If the sphere is minus in power, the term *stronger than* means a stronger minus value. In other words, the higher absolute value. For example, a minus 7.00 D sphere power is stronger than a minus 6.50 D sphere power, whether plus or minus.

*ANSI Z80.1-2020 American National Standard for Ophthalmics—Prescription Ophthalmic Lenses—Recommendations, The Vision Council, Alexandria, VA 22314, 2021.

TABLE A.2 Distance Refractive Power Tolerances for Progressive Addition Lenses

	Sphere Power (When Written in Minus Cylinder Form)	Tolerance for Sphere Power	TOLERANCE FOR CYLINDER POWERS OF: ≥0.00 D ≤2.00 D	>2.00 D ≤3.50 D	>3.50 D
For Progressive Addition Lenses **NOTE:** This does not include variable focus lenses referred to as Degressive and Assistive Power Lenses. (See Single-Vision Lens Tolerances above).	From 0.00 up to ±8.00 D	±0.16 D	±0.16 D	±0.18 D	±5%
	Above ±8.00 D	±2%	±0.16 D	±0.18 D	±5%

TABLE A.3 Tolerances for Cylinder Axis

Cylinder Power Stated Exactly	Cylinder Power Stated in Quarter Diopter Steps	Axis Tolerance in Degrees for the Stated Cylinder Power
<0.12	N/A	Axis tolerances are not specified
=0.12 up to and including 0.25	0.25	±14
>0.25 up to and including 0.50	0.50	±7
>0.50 up to and including 0.75	0.75	±5
>0.75 up to and including 1.50	1.00, 1.25, and 1.50	±3
>1.50	1.75 and above	±2

When measuring for cylinder axis, the lens should be checked at the distance reference point. The distance reference point is that point on a lens where, according to the manufacturer, the distance power is to be measured. The distance reference point may not correspond to the prism reference point, as in the case of progressive addition lenses.

TABLE A.4 Addition Power Tolerances for Segmented Multifocal and Progressive Addition Lenses

Add Power	Tolerance
Up to and including 4.00	±0.12
>4.00	±0.18

TABLE A.5 Determining Unwanted Vertical and Horizontal Prism Tolerances Using the More Traditional Method

Single-Vision, Segmented Multifocal, Degressive, and Assistive Lenses Mounted in the Frame

	Tolerance
Vertical prism or prism reference point (PRP) placement	Within 1/3 prism diopter *or* within 1.0-mm difference between left and right PRP heights in high-powered prescription with no prism ordered
Horizontal prism or PRP placement	Within 2/3 prism diopter (total from both lenses combined) *or* within ±2.5-mm variation from the specified binocular distance PD for high-powered prescriptions

The prism reference point *(PRP)* is that point on a lens where prism power is to be verified. It has also been referred to as the major reference point (MRP).

TABLE A.6 Determining Unwanted Vertical and Horizontal Prism Tolerances Using the Power-Based Method

Single-Vision, Segmented Multifocal, Degressive, and Assistive Lenses Mounted in the Frame

Vertical Prism	
For lenses of ±3.37 D or less in the vertical meridian	Unwanted vertical imbalance shall not exceed 0.33 Δ.
For lenses stronger than ±3.37 D in the vertical meridian	The vertical differences between prism reference points may not be greater than 1.0 mm.
Horizontal Prism	
For lenses of ±2.75 D or less in the horizontal meridian	Unwanted horizontal prism for both eyes combined shall not exceed 0.67 Δ.
For lenses stronger than ±2.75 D in the horizontal meridian	The horizontal difference from the ordered interpupillary distance and the actual measured distance between the prism reference points shall not be greater than 2.5 mm.

Both the more traditional method and the power-based method yield the same tolerance results.

TABLE A.7 Tolerances for Unwanted Vertical and Horizontal Prism

Edged but Unmounted and Uncut: Single-Vision, Segmented Multifocal, Degressive, and Assistive Lenses

For both horizontal and vertical prism…	The tolerance must be within ⅓Δ of the ordered prism power
	or
	the prism reference point placement must be within ±1.0 mm of the ordered position.

TABLE A.8 Tolerances for Progressive Addition Lens Fitting Cross (Fitting Point) Location

Vertical Fitting Cross Heights	
A single unmounted lens A pair of unmounted lenses A pair of mounted lenses	Actual fitting cross height must be within ±1.0 mm of the ordered fitting cross height. Also, both fitting cross heights should be within 1 mm of each other relative to their ordered heights.
Horizontal Fitting Cross Location	
A single unmounted lens A pair of unmounted lenses A pair of mounted lenses	Actual monocular interpupillary distance must be within ±1.0 mm from the monocular interpupillary distance specified.
Horizontal Tilt (as measured using the hidden alignment reference markings)	
Mounted lens	2 degrees

TABLE A.9 Unwanted Vertical and Horizontal Prism Tolerances for Progressive Addition Lenses

Vertical Prism (**NOTE:** When prism thinning is used to reduce lens thickness, the vertical thinning prism is considered as if it were prescribed prism.)	
For lenses of ±3.375 D or less in the vertical meridian…	Vertical prismatic imbalance shall not exceed 0.33 Δ. (**NOTE:** For lens pairs with different cross heights, finding unwanted vertical prism is not as simple as dotting the stronger lens and sliding the spectacles across to read the other lens vertical prismatic effect. The second prism reference point will be at a different ordered height.)
For lenses stronger than ±3.375 Δ in the vertical meridian…	The combined vertical variation from each prism reference point not exceed 1 mm.
Horizontal Prism	
For lenses of ±3.375 D or less in the horizontal meridian…	The combined unwanted horizontal prismatic effects at the prism reference points must not exceed 0.67 Δ.
For lenses stronger than ±3.375 D in the horizontal meridian…	The horizontal variation from the ordered prism reference point location must not be greater than ±1.0 mm for either lens. (**NOTE:** The horizontal prism reference point location is the same as the monocular PD.)

TABLE A.10 Tolerances for Multifocal Segment Location and Tilt

Vertical Segment Location (Segment Heights)	Tolerance
One unmounted lens	Actual height should be within ±1.0 mm from the ordered segment height.
A lens pair (mounted or unmounted)	Actual height should be within ±1.0 mm from the ordered segment height *and* both lens segments in the pair should be within 1 mm of each other.
Horizontal Segment Locations (Near PD)	**Tolerance**
Mounted lens pair	Near interpupillary distance (PD) should be within ±2.5 mm of the ordered near PD. Inset should appear symmetrical and balanced unless specified monocularly.
Segment Tilt (The Amount the Flat Top of a Segment Line Deviates From the Horizontal)	
Mounted lens	2 degrees

For an *E*-line (Franklin-style) bifocal, the optical center of the segment is located at the point on the segment ledge where the ledge is thinnest.

TABLE A.11 ANSI Z80.1-2005 Miscellaneous Tolerances

	Tolerance
Thickness (measured at the prism reference point)	±0.3 mm (when thickness is specified on the order)
Segment Size	±0.5 mm
Warpage	1.00 D (does not apply for points within 6 mm of the eyewire)
Base Curve (using an index reference of 1.53)	±0.75 D (when specified on the order)
Impact Resistance	Capable of withstanding the impact of a 5-8 inch steel ball dropped from 50 inches

When specifying lens center thickness, ANSI Z80.1 defines this as being at the prism reference point (PRP). This will be the optical center unless there is prescribed prism present in the prescription. However, keep in mind that for minus lenses, the minimum thickness will be less than lens thickness at the PRP.

HOW TO DETERMINE IF REFRACTIVE POWER IS WITHIN TOLERANCE

Here is a cookbook method that may be used to see if the refractive power of a prescription is within ANSI standards.

Example A.1

Determine whether the ordered prescription below passes ANSI refractive power tolerances.

Methodology	Example
1. Note the refractive power of the ordered prescription.	1. +4.25 − 1.75 × 180
2. Transpose the prescription into minus cylinder form.	2. The prescription is already in minus cylinder form.
3. Measure the refractive power of the prescription that has been received from the optical laboratory.	3. +4.37 − 1.62 × 178
4. Using Table A.1, determine:	4.
a. What is the tolerance for the cylinder power?	a. Tolerance for a 1.75 D cylinder is ±00.13 D, giving a possible range of from −1.62 to −1.88 D.
b. Is the cylinder power within tolerance?	b. The −1.62 measured cylinder power is within the tolerance range.
5. Using Table A.3, determine:	5.
a. What is the tolerance for the cylinder axis?	a. Axis tolerance for a 1.75 D cylinder is ±2 degrees. This gives a possible range of between 178 and 2 degrees.
b. Is the cylinder axis within tolerance?	b. The measured axis is 178 degrees and thus within the tolerance range.
	Conclusion: The prescription passes refractive power standards.

Special-Purpose Frames

Clip-ons

Clip-ons are supplementary lenses in a mounting that fastens to the frame front of a conventional pair of spectacles. They fit on the outside of the front and may contain sun lenses, plus lenses for reading, prisms, or any other prescription desired for testing or vision therapy purposes.

Drop-ins

Drop-ins are supplementary lenses in a mounting that drops in behind the lenses of a conventional pair of spectacles. They are not always as practical as clip-ons because of their close proximity to the eyelashes. Occasionally, sun lenses in drop-in form are placed behind prescription eyewear. Also drop-in prescription lenses can be placed behind wrap-around sunglass frames.

Entropion Spectacles

Entropion spectacles are equipped with an additional extension behind and roughly parallel to the lower eyewire. This extension is known as a *crutch*, or *gallery*. The crutch supports the skin of the lower lid and prevents the lower lashes from turning in on the eye itself. Fortunately, eyelid surgery is now able to reduce the need for entropion spectacles, making them practically nonexistent. (See also *Ptosis Spectacles*, which are designed for the upper lid.)

Folding Frames

Folding frames are those with hinges placed at the bridge and halfway down each temple. This enables the glasses to be folded to a size equal to one-half the width of the frame front. Such frames are popular for reading glasses and are often seen as over-the-counter readers.

Hinged Front Spectacles

Hinged front spectacles are manufactured with two fronts. The frame front closest to the face is fixed, and the other is hinged and may be flipped down or up. The hinged front usually contains a near addition, although any type of lens could be mounted in the frame.

Lorgnettes

Lorgnettes are a specially designed frame front. Instead of temples, there is a clip or stick with which the glasses may be held in front of the eyes. Lorgnettes are designed to be used for situations when vision at either distance or near must be corrected for short periods of time.

Makeup Spectacles

Makeup spectacles have independent rims that are hinged on the lower edge and may be tipped forward. Each lens may be used alone. When the right lens is tipped down, makeup may be applied to the right eye while viewing with the left and vice versa.

Monocle

A monocle is a single lens mounting held in place by being wedged between the cheek and upper eyebrow area.

Ptosis Spectacles

Ptosis spectacles are equipped with a crutch in the form of a stiff metal or plastic-coated wire that is positioned behind and roughly parallel to the upper eyewire. The crutch supports the skin of the upper lid and prevents the lid from drooping closed. The present state of oculoplastic surgery makes these types of spectacles rare.

Recumbent Spectacles

Recumbent spectacles are equipped with reflecting prisms that enable a person lying flat on his or her back to see straight ahead while looking straight up. These can be useful for those wishing to read while being required to remain on their backs for long periods of time. The prisms must be perfectly aligned or diplopia occurs, making wear impossible.

Reversible Spectacles

Reversible spectacles are appropriate for an individual who is only able to see out of one eye yet who needs different corrective lenses for distance and near. They can be used when multifocals are inappropriate or undesirable. Reversible spectacles are designed so that they may be worn upside down. Temples usually swivel at the endpiece so that the earpieces can be turned up or down. Alternate means of obtaining a reversal are also available.

APPENDIX C

Correcting Vertical Imbalance for Both Distance and Near Viewing

CORRECTING NEAR VERTICAL IMBALANCE FOR SEGMENTED MULTIFOCAL LENSES AT BOTH DISTANCE AND NEAR

Just as there is vertical imbalance in the lower half of an anisometropic lens pair, so also is there vertical imbalance in the upper half. With segmented multifocal lenses, this is usually less of a problem because the optical centers (or major reference points [MRPs] when prescribed prism is present) may be moved upward in the lenses. However, this will increase the amount of vertical imbalance in the near viewing area. Therefore, vertical imbalance correction for both distance and near viewing should not be ruled out for segmented multifocal lenses. The procedure for counterbalancing this imbalance is basically the same as it is for progressive addition lenses. First, the distance viewing level is determined and the imbalance calculated by taking the distance from the MRPs of the lenses to the distance viewing level. (MRPs are the equivalent to prism reference points [PRPs].) The procedure for addressing this problem is described below for progressive addition lenses and may also be followed for segmented multifocal lenses.

CORRECTING VERTICAL IMBALANCE FOR PROGRESSIVE ADD LENSES AT BOTH DISTANCE AND NEAR[1,2]

With progressive addition lenses, we cannot move the PRPs (MRPs) higher in the lens to lessen vertical imbalance in the distance portion of the lens. With progressive addition lenses, the PRP is, by necessity, at the beginning of the progressive. Therefore, if there is too great a distance from the PRP to the location in the lens where the eyes are looking during distance vision that causes significant vertical imbalance, then the imbalance in the distance could be a problem.

Because the fitting cross, where the pupil is located, is above the PRP, there will be vertical imbalance at the fitting cross when right and left lenses have different powers. To compensate for this, first, the amount of vertical imbalance is calculated for the level of the fitting cross. (Some advocate using the location of the distance reference point (DRP) instead of the fitting cross.[2] The important thing is to determine what level the wearer is primarily using for distance viewing and use that location.) The correct sequence is to correct vertical imbalance first for distance and then for near. The amount of compensating prism calculated at the level used for distance viewing is first applied to the entire lens. Here is an overview of the procedure.

Start with the distance imbalance. We will assume we are using the fitting cross as the location where distance viewing is taking place. (The level of the DRPs could just as easily have been chosen. The procedure is still the same.) To calculate vertical imbalance at the level of the fitting cross, begin by finding the distance from PRP to the fitting cross. In most cases and in the example following, the distance from the PRP to the fitting cross will be 4 mm. Keep in mind that, in the absence of prescribed prism, there are equal amounts of vertical prism at the PRPs. This is because there will be either zero prism or equal amounts of yoked base-down vertical prism for the purpose of thinning the lenses.

Next, the amount of vertical imbalance at near is calculated using the distance from the PRP to the near reference point (NRP).

Lastly, the slab line is positioned.

Here is an example to see how the process works.

Example C.1

A patient has the following prescription:

R : +2.00 DS
L : +6.00 DS
Add : +2.25 D

The progressive lens has the fitting cross 4 mm above the PRP, and the distance from the PRP to the NRP is 12 mm.

A. How much vertical prism would be ground on which lens to eliminate vertical imbalance in the distance portion at the fitting cross?
B. How much slab-off prism would be ground on which lens to eliminate vertical imbalance at the NRP?

Solution

To solve part A: Find the vertical imbalance at the fitting cross by taking the distance from the PRP to the fitting cross and multiplying it by the power in the 90-degree meridian. This distance is 4 mm, or 0.4 cm. For the right lens, the prism amount at the fitting cross is

$$\Delta = cF$$
$$\Delta = (0.4)(2)$$
$$= 0.80\Delta \text{Base down}$$

For the left eye, this is

$$\Delta = (0.4)(6)$$
$$= 2.40\Delta \text{Base down}$$

The difference is 1.6Δ more base down in the *left* eye. This may be equalized for distance vision by grinding 1.6Δ of base-down prism in the *right* eye.

To solve part B: Find the vertical imbalance at the NRP by taking the distance from the PRP to the NRP and multiplying it by the power in the 90-degree meridian. This distance is 14 mm, or 1.4 cm. For the right lens, the prism amount at the NRP is

BOX C.1 Steps to Correct for Vertical Prism Imbalance at Both the Fitting Cross and Near Viewing Area

1. *Calculate Imbalance for Distance*
   Calculate vertical imbalance at the fitting cross (or one may substitute the distance viewing level).
   a. Using Prentice's rule ($\Delta = cF$), find the vertical imbalance at the level of the fitting crosses by multiplying the distance in centimeters from the prism reference point (PRP) to the fitting cross by the difference in distance powers in the 90-degree meridians for left and right lenses.
   b. Use the amount of differential prism found and have it applied as base-down prism to the most minus or least plus lens.
2. *Calculate Imbalance for Near*
   Assuming the full amount of vertical imbalance is to be corrected at near, calculate this imbalance at the reading level. When calculating the full imbalance for progressives, the reading level would be at the level of the near reference point (NRP).
   a. Find the distance from the PRP to the NRP.
   b. Multiply this distance in centimeters by the difference in powers in the 90-degree meridians for left and right lenses as in step 1 above. (It is not necessary to consider the add power. The difference in powers in the 90-degree meridians will be the same.)
   c. This amount of differential prism would normally be applied as a traditional (base-up) slab-off correction on the most minus or least plus lens. However, the slab off must also compensate for the base-down vertical prism included for the distance imbalance. So the correcting amount of imbalance for the distance must be added to the slab-off prism calculated for near.
3. *Yoked Base-Down Prism*
   What about yoked base-down prism to thin the lens?
   a. If the lab chooses to thin the lens using yoked base-down prism, that prism will be added to both lenses. The yoked vertical prism amount will appear in both lenses at the level of the PRPs. Because the yoked base-down prism is of equal amount for both lenses, the imbalance corrections for both distance and near will be unaffected.
4. *Slab Line Location*
   Determine the desired vertical location for the slab-off line.

$$\Delta = cF$$
$$= (1.2)(2)$$
$$= 2.40\Delta \text{Base up}$$

For the left eye, this is

$$\Delta = (1.2)(6)$$
$$= 7.20\Delta \text{Base up}$$

For the calculated *imbalance* at near, the difference is 4.8Δ more base up in the left eye. Therefore, the amount of slab-off prism would normally be 4.8Δ base up of traditionally calculated imbalance prism over the right eye. (The right eye is the least plus-powered lens.) However, this amount does not include compensating for the 1.6Δ of base-down prism that was ground over the entire right lens to compensate for vertical imbalance in the distance at the fitting cross location. Since this is ground on the entire right lens, it must be offset in the near viewing area. Therefore, the amount of slab-off prism would be 4.8Δ Base up of traditionally calculated imbalance prism over the right eye *plus* 1.6Δ slab-off base up over the right eye. So the total amount of slab-off prism ground would be 6.4Δ of base up prism on the right eye. Let the optical lab determine the amount of yoked base-down prism required to thin the lens. (For a summary of these steps, see Box C.1.)

The location of the slab line should be chosen to meet the needs of the wearer as determined by the eye care practitioner. (This is explained in Chapter 21, *Anisometropia*, under the section titled *Where Should the Slab Line Be Positioned?*)

If the full amount of calculated vertical imbalance is to be used, the eye care practitioner may choose to specify the location where he or she desires zero vertical imbalance, such as at the NRP. If there is good communication with and confidence in the lab, the practitioner may then ask the lab to do these needed calculations in order to achieve zero vertical imbalance results for both distance- and near viewing levels. Then when verification is done, the glasses are placed in the lensmeter first at the desired distance viewing level for one lens. The amount of vertical prism is noted. The glasses are then slid horizontally on the lensmeter table to the other lens. The amount of vertical prism noted in the second lens should match that of the first lens. The procedure is repeated for the near viewing level.

REFERENCES

1.. Carl Zeiss Vision Web site, n.d. http://www.zeiss.de/4125680F0053A38D/Contents-Frame/C01EC718EF317EF5C1256CFD002B9E3D [Accessed 4/14/2010].
2.. Cook PR. *A Question of Balance: Dr. Cook's Recipe for Adjusting PAL Imbalance, 20/20*; April 2013.

PROFICIENCY TEST ANSWER KEY

Chapter 1

1. c. Even though many frames are a combination of both plastic and metal materials, the combination frame is classically unique in appearance, with top rims on a metal chassis.
2. b. The reinforcing arm is the feature that differentiates a semirimless from a rimless frame.
3. c. Half-eye frames sit low on the nose and have about half the vertical dimension that a normal frame has. They allow the wearer to look over the top of the glasses for distance viewing.
4. b. Lorgnettes are like frame fronts without temples. A single lens in front of one eye is called a monocle.
5. e. Even though the answer is cellulose acetate, some dispensers will call almost any plastic frame a zyl frame.
6. c. Riding bow. Riding bow and cable temples both curve all the way down behind the ear. The riding bow is made from a plastic material, and a comfort cable is made from a metal material.
7. b. Modified saddle bridge. The differentiating factor between saddle and modified saddle bridges is the presence of nose pads made as part of the frame bridge from the same material as the frame itself.
8. b. The large sheets of cellulose acetate may be varicolored and layered, giving artistic variety to cellulose acetate frames.
9. d. Propionate is like cellulose acetate but made from granules. These often-colorless granules are heated and molded. Then the frame parts may be dyed to a desired color.
10. e. Optyl is an epoxy resin material.
11. b. It may seem counterintuitive that a frame is classified pure titanium yet contains less than 100% titanium. The reason is that the remaining 10% will allow for frame properties desired or needed for ophthalmic metal frames.
12. b. Polycarbonate does not adjust, stretch, or shrink. Aluminum is hard to adjust but it is adjustable.
13. d. Nickel is notoriously allergenic. It may still be used in frames if the frame is coated, although people who have severe allergies may still be bothered by it.

Chapter 2

1. b. False. The effective diameter is twice the longest radius as measured from the boxing center.
2. a. True. For a round frame shape, the horizontal and vertical measures (A and B) are equal. Subtracting one equal number from the other gives a zero result.
3. b. The wearer's PD will only occasionally be the same as the A plus the DBL. Frame PD is a commonly used synonym for the geometric center distance, which is equal to A + DBL.
4. a. The horizontal midline or 180-degree line is at half the frame B dimension. If half the B dimension is greater than the seg height, the seg height is subtracted, giving the seg drop.
5. c. Frame (or lens) difference = A − B
6. e. 42 mm. Frame difference = A − B. In this case 8 = 50 − B, so B = 50 − 8 = 42 mm.
7. c. Frame difference = A − B = 47 − 30 = 17
8. a. The effective diameter of a lens is found by doubling the distance from the geometric center of the lens to the apex of the lens bevel farthest from it. This is called the *longest radius*.
9. d. 52 mm. A circle has the same distance from its boxing center to its edge in every direction. So twice the longest radius always gives the same number and equals the A dimension of the frame. So, what is the B dimension of this frame? The answer is also 52 mm.
10. c. The geometric center distance = A + DBL, which in this case is GCD = 52 + 17 = 69 mm.
11. b. The ED of a horizontally oriented oval shape has the longest radius in the 180-degree meridian. Twice this longest radius is equal to the A dimension of the frame.
12. a. A square has a longer distance from the center to a corner than from the center to the left or right side. Twice the distance from the center to the corner is the ED, which will be greater than the A dimension.
13. c. Although pure gold is gold in color, that color changes when mixed with another kind of metal.
14. a. Fine gold is the name given to 100% pure gold.
15. e. Each major part of a safety frame must be marked Z87-2, plus the manufacturer's name or logo. The American National Standards Institute (ANSI) standard for safety frames is designated by the code Z87.

Chapter 3

1. b. False. In some circumstances, the person measuring may cover one of the subject's eyes at a time if the subject's eyes turn in or outward.
2. f. Given the high number of times when monocular PDs are important, some feel that it is advisable to routinely use monocular PDs.
3. b. No. The limbal edge should only be used for binocular PDs when other methods fail and then only by using the outer limbal edge of one eye and the inner edge of the other eye. The results may still not be very accurate. It would be better to use another method, such as a corneal reflection pupilometer.
4. a. True. Even though the corneal reflex is not always exactly in the center of the pupil, this method is currently acceptable.
5. e. The pupil center locations should be marked on the lenses. However, the procedure to follow as outlined in Box 3.2 is the correct procedure.
6. d. Large segment lenses may mask the problem, even though the segments are unevenly placed. If the wearer is willing, switch to a lens whose near viewing area is not visible to an observer.
7. c. $\frac{64-59}{2} = 2.5\,\text{mm}$
8. c. The farthest working distance expected for an add power higher than 2.50 D would usually be expected to be the reciprocal of the add power, which is

$$\frac{1}{4.00} = 0.25\text{ m or }25\text{ cm}$$

9. b. As the seg inset increases, the near PD decreases. For a plus lens distance correction, as the eyes converge inward, the plus lenses cause a base-out prismatic effect. This causes the eyes to turn further inward.
10. d. 4.0 mm. To be exact, the inset per lens would be

$$5 \times \frac{3}{4} = 3.75\text{ mm}$$

Compare this problem to Example 3.2. If neither were rounded, the results will be the same.

11. a. The working distance is the distance from the spectacle plane to the position where the near viewing materials are located. When using a PD ruler, the ruler will be held at the location of the spectacle plane.
12. c. Because the distance lens power is so low and the PD is between 62 and 68 mm, the easiest way to answer this question is to use the Three-Quarter Rule. The accommodative dioptric demand is $1/0.25 = 4.00$. Three-quarters times the accommodative demand of 4.00 D results in a 3.0-mm inset per lens.
13. c. The dioptric demand is 1/0.20 or 5.00 D. Using the Three-Quarter Rule, the inset per eye is $3/4 \times 5$, or 3.75 mm. The near PD would be $64 - (2 \times 3.75) = 56.5$ mm.
14. d. All the normal rules apply for finding the near PD. The optical centers of the +5.00 D single-vision lenses are horizontally positioned just as if they were the centers of the segments of a bifocal lens, but the near PD must be measured at a 20 cm distance from the spectacle plane.
15. d. Since the distance lens is high minus in power, the insets would be decreased slightly, increasing the near monocular PDs slightly.

Chapter 4

1. c. A deeper frame is more complimentary to a long face. In a sense, the frame "covers" part of the face. Covering more of a long face vertically gives the illusion of reducing its vertical length.
2. a. Although a rimless frame may be appropriate for a person with a round (vertically short) face because it does not appear to cover as much of the face, there are also other alternatives as listed in the chapter. Answers b and c make the face look shorter still, and a large, dark, bold frame can easily overpower the face.
3. b. Choose a frame that does not draw attention to itself. The upper part of the face has more "weight" to it. A frame that does not increase that upper facial emphasis will not contribute to facial imbalance.
4. a. An appropriate frame is one that draws the observer's eye to the upper part of the face, counterbalancing the wide lower part of the frame without repeating and emphasizing facial lines.
5. a. Rounded corners will cut off the lens edge where it would otherwise be thickest.
6. c. Because glasses will help to emphasize the upper part of the face, they will balance the base-down triangular face.
7. a. This is a frame that is narrow vertically and covers less of the vertical dimension of the face, shortening the face less than one with deep lenses.
8. a. In most circumstances, the upper rim of the frame complements rather than competes with the line of the eyebrows.
9. b. False. Accessories are normally chosen to complement clothing colors.
10. a. True. According to traditional styling rules the answer is true. However, it should be kept in mind that fashion trends may temporarily come into conflict with classical rules of frame selection. Aside from optical constraints, personal choices of style and color ultimately belong to the individual wearer.
11. b. False. This is entirely a personal choice.
12. b. False. When in doubt, it is advisable not to error on the side of possibly overpowering a face with a frame.
13. a. Covering more of the vertical dimension of the nose gives the illusion of shortening it.
14. d. Decreasing the vertex distance and increasing the pantoscopic tilt will both bring the progressive lens viewing corridor closer to the eye and will increase the field of view for reading. Not enough depth in the nasal portion will cut off some of the near viewing corridor, so adequate depth nasally is needed.
15. b. A squared-off corner means the corner is further from the optical center of the lens than if it were rounded. Since it is further from the optical center, the edge of the lens at the location of the corner will be thicker.
16. b. Choosing a frame with an ED very much larger than the eye size of the frame will require that a larger lens be used. For plus lenses, a larger lens will result in a thicker, heavier lens.
17. c. If the distance from the eye for a high plus-powered lens changes, it changes the effective power of the lens. Library temples do not hold the position of the lenses as well as other temple styles.
18. b. Less. High plus lenses tend to make the wearer's eyes look bigger and may make it look like more makeup is being worn than the wearer may have intended.
19. b. 1.0 mm.
20. f. An antireflection coating will eliminate internal reflections from front and back surfaces and does the best job.
21. b. A design that holds the lenses in place with a nylon cord will be more likely to have the lens dislodged with the rough treatment some children may subject them to.
22. b. False. Safety frames are capable of being made stylish and comfortable—so much so that some people end up wearing their safety glasses for full-time wear.
23. b. False. Using this method will lead to an unbalanced selection of frames for the dispensary.
24. d. Placing responsibility for avoiding discontinued frames on the frame representative should be financially advantageous for both parties. That said, the success of this arrangement will still depend upon the care taken by the individual representative.
25. d. We are looking for a frame with a small ED to reduce center thickness. We are also looking for a frame that is closer to a round shape with the vertical (B) dimension not a whole lot smaller than the horizontal (A) dimension. This prevents the top and bottom of the lens edges from being thick, since a narrow frame shape will have the top and bottom edges closer to the thicker center of the lens. Lastly, if there is a decision between a smaller eye size with a larger bridge size instead of a larger eye size and a smaller bridge size, the smaller eye size is preferable.

Chapter 5

1. False. The level to measure from is the level of the box that encloses the frame shape. The level of the lowest part of the inside bevel of the lower eyewire or lens.
2. c. When there is prescribed prism, the MRP is that point on the lens where the prescribed prism is correct.
3. a. Positive face form so that the two surfaces at the optical center are perpendicular to the line of sight passing through them and the center of rotation of the eye.
4. b. Even though the lenses are decentered outward and the optical expectation would call for negative face form, this should not be done. The result is cosmetically unacceptable.
5. d. This is meant to cause the optic axis of the lens to pass through the center of rotation of the eye.
6. a. True. This procedure fulfills the rule stating that the MRP should be dropped 1 mm for every 2 mm of pantoscopic tilt.
7. a. The location of the MRP of the lens should be lowered when pantoscopic tilt is present.
8. c. Half the pantoscopic tilt is 5 mm. The MRP height will be the measured height of 26 mm minus 5 mm, or 21 mm.
9. c. Normally we would drop the MRP 6 mm because of the pantoscopic tilt. However, this would place the MRP below the middle of

the lens. The middle of the lens is found at a height of half the B dimension, which is 22 mm—the lowest that the MRP should be placed. The calculated height is 20 mm, which is 2 mm below the permissible point. It is not advisable to move the MRP height below the horizontal midline of the glasses unless the lenses are intended exclusively for near work.

10. d. To measure vertex distance. It is also possible, and easier, to measure vertex distance using a tablet device with appropriate software.
11. b. The farther the segmented lens is from the eye, the harder it is to see over the top of the segment, making it seem higher.
12. c. It would be feasible to use a Fresnel press-on lens to change the power of the distance lens if it covered the entire lens. It would not be possible to use a Fresnel, press-on segment.
13. a. Increasing the base curve causes a lens to steepen and arch out away from the eye.
14. b. One diopter change in base curve changes vertex distance by approximately 0.6 mm. Of course if the eye size is small, the vertex distance will be smaller than 0.6 mm and vice versa.
15. e. Trifocal height is lowered 1 mm below the lower edge of the pupil.
16. c. Round segments are moved up 1 mm so that the person wearing them will have more reading width sooner when lowering the eyes to read. Much higher may interfere with distance vision.
17. d. The segment moves 0.3 mm in the direction of the apex of the prism for each diopter of vertical prism prescribed. Also note that segment height is normally measured in 1-mm increments—not 0.5-mm increments.
18. Of the answers given, c is the best answer. Normally bifocal heights are given in 1-mm increments. If specified in 1/2-mm increments, the answer would be to lower the right bifocal 0.5 mm and raise the left bifocal 0.5 mm from their measured values. A third alternative would be to leave the right bifocal as measured and raise the left bifocal by 1 mm.
19. e. When adjusting bifocal heights because of the presence of prescribed vertical prism, the net amount of change must be considered from a binocular standpoint. In other words, the total amount of prism for left and right eyes combined is 6Δ. So the amount of change will be $6 \times 0.3 = 1.8\Delta$. When rounding, keep this in mind. Otherwise a wrong amount of compensation might be made. Fortunately, this example works out okay. The main thing that looks confusing is because the measured heights and compensated heights appear to have traded places!
20. c. This assumes a 13-mm distance between upper and lower segs. If the seg height is 21 mm, add 13 to 21 and subtract this number of 34 from the B dimension of the frame. So, $44 - 34 = 10$ mm of vertical segment space remaining at the top of the lens.
21. d. The pupil should be split with the bifocal line to assure that the child is looking through the bifocal addition while reading and not over the top of the segment.
22. c. However far above or below the old segment line is from the reference point (in this case the lower limbus), that is the amount that must be added to or subtracted from the reference point height to find the new segment height. Point of caution: The dispenser must be confident that the previous measurements are still appropriate.
23. a. Increasing the pantoscopic angle moves the segment closer to the eye. This allows the wearer to be able to see over the top of the segment more easily.
24. d. The amount of change in the A dimension between the sample and ordered frames should be divided by 2 and added to or subtracted from the measured height. Here, the ordered frame is 2 mm larger, so the measured height of 21 should have half that amount added, resulting in a 22-mm height.
25. d. Segment height may be compensated when using the wrong eye size mathematically. Seg height compensation for a wrong bridge size requires being able to estimate at what height the frame will rest with the correct bridge size.
26. c. A common meaning for "semi" is half. A semifinished lens blank is half finished.
27. c. There is zero decentration per lens. So the MBS is the effective diameter plus 2, or 54 mm.
28. c. Frames which have either round or oval shapes have an effective diameter that is the same size as the A dimension of the frame.
29. e. A round eye size has and effective diameter equal to the eye size of the frame. So the ED + 2(dec) + 2 = 50 + 6 + 2 = 58 mm.

Chapter 6

1. c. The right lens, designated here by OD, should be listed first, not second.
2. b. Minus one diopter should be written as −1.00 and not as −1.0 or −1, and +4.5 should be written as +4.50.
3. a. The cylinder axis should have three numbers. The number twelve should be written as 012 and not as 12 or 12 degrees. Do not include a degree sign as it may be mistaken for a zero.
4. a. The cylinder power should be written as −0.75.
5. d. We are most interested in how the vertical meridians of the two lenses compare. If they are basically the same, begin with the right lens.
6. b. By itself, the presence of cylinder in the prescription will not cause the optical center locations to be incorrectly placed.
7. b. Placing the optical centers at the same location as in the existing glasses when the powers are high will duplicate the prismatic effect in the existing glasses. The prism that exists in the existing glasses is likely prescribed prism, especially since the existing glasses are being successfully worn.
8. a. For reading lenses in minus cylinder form, we always start by turning the power wheel high enough in the plus direction until both sphere and cylinder lines are blurred out. That way we are moving in a minus direction and the value of the minus cylinder will be measured in a minus direction.
9. b. Starting in high minus means we are moving in a plus direction and the cylinder value will be read as plus.
10. a. Plus cylinder form. When going from −3.00 to −2.50, the power wheel is moving in a plus direction.
11. a. Front surface multifocal add powers are measured using the difference between front vertex distance and near powers. Back surface multifocal add powers are measured using the difference between back vertex distance and near powers.
12. d. The lensmeter is measuring the vergence of light as it leaves the location of the back vertex of the lens.
13. c. $+6.625 - (+4.875) = +1.75$
14. b. Not checking the height of the optical center of the existing lens could result in unwanted vertical prism.
15. b. Absolutely false! An explanation of lens materials—especially lens material safety—needs to happen each time an old pair of lenses is being replaced. Situations change and lens materials may need to change with them.
16. a. The higher the cylinder power, the more of a decrease in image quality occurs when the cylinder axis is off.
17. a. The prescription must fail unwanted horizontal prism requirements using two different criteria. Both of these must fail for the prescription to fail.
18. b. One lens may be off by 1 mm. But if one lens is 1 mm too high and the other is 1 mm too low, then the difference in heights is two millimeters. This difference is unacceptable.

19. c. Because of the location of the lens optical centers compared to her PD, her present glasses have a total of about 3.25Δ of base-in prism. Removing this amount of prism would be a very big change. Order the 71-mm PD, and note what was done and why in the record.
20. e. When right and left lenses are considered as a pair, the total amount the PD should be off is 2.5 mm. However, it could still pass. It must also manifest unwanted prism greater than 0.67 prism diopters.
21. b. No. The sphere power is off by 0.37 D. The allowable tolerance is ±0.13 D.
22. a. Yes. The sphere power is exactly as specified.
23. a. Yes. The cylinder power is off by 0.10 D and the allowable is ±0.15 D.
24. a. Yes. The cylinder is off by 0.05 D and the permissible is ±0.13 D.
25. b. No. The axis is off by 3 degrees and the allowable is 2 degrees.
26. a. Yes. The axis is off by 4 degrees and the allowable is ±5 degrees.
27. a. Yes. The prescription shows 0.25 prism diopters of unwanted vertical prism, but the allowable is 0.33 prism diopters.
28. a. Yes. Even though the distance PD is off by 4 mm and only 2.5 mm is allowable, the amount of horizontal prism is only 0.10 prism diopters and the allowable amount is 0.67 prism diopters. Both criteria must fail for the prescription to fail.
29. a. Yes. The near PD is off by 2.0 mm, but the allowable PD is 2.5 mm.
30. a. Yes. Both seg heights are only off by 0.5 mm each and both are in the same direction. A difference of 1.0 mm is allowable.
31. b. By placing the auxiliary prism in the opposite base direction from that of the prism in the spectacles, it neutralizes the prism and brings it into view on the lensmeter screen.
32. a. Moving the larger prism component to the center of the screen will assure that, under most circumstances, the other prism component will also be visible on the viewing screen and can be measured.
33. c. If there is cylinder in a prescription, it is normally found on only one lens surface—normally the back surface. (In some lens prescriptions for aniseikonia, it is conceivable that a cylinder might be found on both surfaces to reduce meridional magnification differences. However, this is rare.)

Chapter 7

1. b. False. Remove the lens and start over. Otherwise the frame will not heat evenly and the lens could be affected.
2. c. Talcum powder will keep salt from clumping and sticking to the frame. However, the best solution is not to use a salt pan. Rather use a hot air frame warmer.
3. a. A cylinder axis could still be incorrect, even if the lens multifocal segments are exactly symmetrical.
4. b. Optyl frames can take higher heat. If they have cooled and are reheated, they will return to their original shape.
5. b. Cellulose acetate. If previously stretched, it will shrink if plunged into cold water. Even when new, it may shrink some—although not always.
6. a. Polyamide frames should have lenses cold snapped into place. Once the lenses are in, the frame could be heated some if the lenses are not secure enough. The frame will shrink and tighten around the lens.
7. b. Optyl frames need to be heated for lens insertion. They expand when heated. These frames should then be allowed to cool slowly. Cooling them suddenly will stop them from shrinking back down, leaving the lenses loose.
8. a. True. Polycarbonate lenses are not able to be adjusted.
9. a. 0.4 mm larger. This amount has varied from past recommendations. This may be because of who owns the rights to Optyl material and how their manufacturing methods may vary from previous methods.
10. e. The lens offers the least resistance here and exits from the front.
11. c. If we were speaking of eyewire-forming pliers, the answer would have been b.
12. b.
13. a. The cord will slip over the front curve of the lens and into the groove more easily.
14. d. A dental pick is well suited to get into the lens groove and snag the cord.
15. a. The lens should not be easy to rotate in the frame, either.
16. b. False. Although it may temporarily tighten, it has lost elasticity and will soon loosen up again.
17. c. The lower frame rim is tilted, which is called being *rolled*.
18. d. A sphere lens does not give a good indication of being rotated unless it has been decentered. In this case unwanted vertical prism could be manifested if the refractive power is high enough.
19. c. If the lens is edged with the cylinder off-axis, then rotating the lens with lens rotating pliers till the axis reads correctly on a lensmeter will distort the frame shape.
20. b. Checking to see if the bifocals are straight is a good first step. If the cylinder axes for both lenses are correct and the lens shapes are symmetrical with one another, the lenses are not rotated.
21. a. Polycarbonate lens edges will whiten with acetone. Cellulose acetate will melt. It should not be cleaned with acetone, but acetone may be used for other purposes with it. Acetone may degrade an antireflective coating.

Chapter 8

1. a. Truing and standard alignment of frames are synonyms.
2. b. Hot salt or glass beads can be harmful to lenses that are coated.
3. b. Most frames will have some face form, so not touching the eyewires nasally is acceptable as long as the distance from the nasal eyewires to the ruler is equidistant.
4. a. Horizontal misalignment is not always easy to detect. A rotated lens in particular requires a close comparison between right and left lenses on how shapes might be tilted.
5. c. If, when the two lenses are viewed from the side, they resemble an X, the frame front is said to have X-ing.
6. e. A skewed bridge usually only appears after the glasses have been dispensed and something has happened to them.
7. d. Lenses out of coplanar alignment are a synonym for variant planes.
8. b. It is counterproductive to spread the temples beyond the width of the wearer's head and then have to bring the temples back in later.
9. b. Do not file the endpiece. If the temple is ever to be replaced, filing the frame front only makes future alignment harder.
10. a. Not only is it permissible, often times it is unavoidable.
11. e. All of the above are true.
12. b. When glasses are placed right side up on the table, if one earpiece (bent-down portion) is bent down a different amount than the other earpiece, a true comparison of pantoscopic angle equality (temple parallelism) is not possible.
13. a. Unequally angled bent-down portions will invalidate the test for temple parallelism.
14. c. The bend for pantoscopic angle should be in the metal hinge, not requiring heat.
15. e. Of the pliers listed above, e is the best choice. However, endpiece-angling pliers would also work. In many cases endpiece-angling pliers may work better, depending upon frame design.

16. a. True. Temple fold angles and pantoscopic angles are both done by bending the hinge, but each of the two bends are in different directions and 90 degrees away from each another.
17. True. The British call this angle the "let back." In the United States, this angle is usually called "open temple spread." "Let back" is perhaps more descriptive.
18. e. The procedure listed in e is one used to bring the temple inward, or decrease the temple let back. Answer d should only be used when other methods fail.
19. a. Retroscopic tilt is almost never appropriate.
20. b. False. Temples may cross below the center of the frame to keep the temple ends from resting on the lenses or may cross above the center of the frame to allow the glasses to fit in a standard case.
21. b. False. This method is sometimes the best method since it will not mark the frame . Also, pressure on the lens is against its outer edge and in the same plane as the lens. This makes lens breakage less likely.
22. b. The vertical angle between the long axis of the nose pad and the frame front. It is seen when viewed from the side.
23. b. Although the splay angle may be viewed from the top or the bottom, it is usually better seen from the bottom.
24. c. When the frame is worn, the long axis of the nose pad should be perpendicular to the floor. This allows for best distribution of the weight of the frame. Since the frame normally has pantoscopic tilt, the vertical angle and pantoscopic tilt are equal.
25. c. With a round nose pad, there is no long axis, so there can be no vertical angle.
26. a. The frontal angle. It is viewed from the front, and the distance between pads widens at the bottom just as the lower part of the nose is wider than the upper part.
27. b. 1 mm. Note that this is the distance from the face of the pad to the eyewire and not from the back of the pad to the eyewire.
28. b
29. a. The frontal angle.
30. c
31. e. X-ing.
32. c. At the time of this writing, Trivex is the least likely to develop stress fractures at the mounting points of rimless drilled mountings.
33. c. Rimless holding pliers are used to reduce the possibility of chipping or cracking a lens during the adjustment process. The second pair of pliers are used as the bending pliers.

Chapter 9

1. e. If the nose pads are spread too far, the frame will be lower on the face.
2. b. Remember, if the right side is up, bend the right temple up—UP, UP.
3. b. Even though the problem could be solved by increasing the distance between pads, it would also be possible to first consider increasing the pantoscopic angle and/or decreasing the vertex distance.
4. b. Lowering the vertical position of the two nose pads on the frame will raise the height of the frame on the wearer's face instead of lowering it.
5. c. The vertex distance is the distance from the front surface of the eye to the back surface of the spectacle lens.
6. d. Nose pads that are too close together will cause the frames to be farther from the face.
7. d. For answer a, choosing a different frame basically starts over in hopes of finding a better fitting frame. For b, moving the adjustable pads farther away from the frame front moves the whole frame front further away from the face. For c, when pantoscopic tilt is increased, in addition to moving the lower part of the frame closer to the face, increasing pantoscopic tilt moves the top of the frame farther from the face. This is because the frame front pivots on the nose where the frame front rests.
8. c. If the lens is too far IN, move the temple on that same side IN.
9. c. This type of pressure will force the frame forward.
10. b. False. Narrowing the distance between pads will cause the frame to sit higher and somewhat further away from the face.
11. b. False. Strap bridges do increase the weight-bearing area yet are still adjustable like the pads they replace.
12. b. If the frame sits too far to the LEFT, move both pads to the LEFT.
13. d. If the *pads* are too far to the wearer's left, this will cause the frame to be too far to the right. The situation would be corrected by moving the pads to the right (*Frame* to the RIGHT, move pads to the RIGHT). A crooked nose could also cause the problem.
14. a. True. This is shown in Figure 9.30.
15. a. True. Remembering this two-move principle simplifies the approach to adjusting nose pads.
16. c. Nose pads that still hurt after they have been positioned flat on the nose with an otherwise correct adjustment are usually due to frame/lens weight. The problem may be avoided with an appropriate frame and lens selection. Putting larger pads on the frame may work but is not ideal. The problem was caused during frame and lens selection.
17. c. See Figure 9.28.
18. d is false. Adjusting spring hinges with less temple spread than normal was appropriate when spring temples first came out. It is no longer appropriate, since spring temples are adjusted exactly like regular, nonspring temples.
19. a. True. There is only so much room behind the ear. Choose a temple that does not take up much room and stays out of the way of the behind-the-ear hearing aid.
20. a. True. The procedure is as described or with right and left switched in the description if the wearer is left-handed.
21. a. The more widely spread temple allows the lens to come in closer to the face.
22. a. The tighter temple is squeezing that side of the face and pulling against the back of the ear on the same side and the side of the nose on the opposite side.
23. b. As in the previous question, the tighter temple is squeezing that side of the face and pulling against the back of the ear on the same side and the side of the nose on the opposite side.
24. c. Although this may seem counterintuitive, too much pressure on the sides of the head anterior to the ears will cause the frames to want to move forward to relieve the tension on the frame.
25. c. Initially one might think that either b or c could be correct. That might be the case, except we know that there is too much pantoscopic tilt. Bending the left temple downward only increases the pantoscopic tilt, making the frame have even more pantoscopic tilt than it does already.
26. c. Widening the distance between pads not only will drop the frame height, but also allow the frame to sit closer to the face—and lashes.
27. b. These two points above the ears are two of the three parts of the fitting triangle. The third point is the crest of the nose.
28. b. False. Adjusting the temples to follow the depressions in the sides of the head will increase the contact area, increasing friction and decreasing pressure.
29. c. Frames with spring hinges are to be adjusted in the same manner as for nonspring hinge temples.
30. d. Red marks are indicators of high pressure. High pressure at the front edge of the pad means that the splay angle is too great and needs to be decreased.

Chapter 10

1. c. There are several options to use—some better than others—if the barrel threads have been damaged. For example, although a glass screw and hex nut may be used, it is the least satisfactory of the options listed in this question, even though it will work and is an easy fix.
2. b. All other answers except b are commonly used methods for holding a loosening screw in place. If this problem is consistent for a particular type of frame, discontinue selling the frame.
3. b. Acetone will melt most plastic frame materials and should not be used.
4. d. See Box 10.2 for possible methods of removing a broken off screw.
5. a. True. These screws are made to snap off, thereby breaking closer to the barrel. This makes it much easier than trying to clip off the screw close to the barrel.
6. a. The titanium screw must enter the barrels exactly straight. At even a slight angle, the screw will bind.
7. c. The threads in the barrels are in the bottom rather than the top. Less drilling is required when drilling from the bottom. Either cutting oil or, simply, even 3-in-1 oil should be used.
8. c. The tapered tip allows the screw to pass through the smaller opening where the holes are only partially overlapping.
9. b. Bushings help to pad between the lens and the screw for less stress on the lens.
10. b. False. The epoxy coating is made to break loose with enough torque on the screwdriver so that the screw may be removed. The coating consists of small resin and hardener bubbles. Not all break and mix with the first tightening. Thus when removed and replaced, they will still have enough glue power to keep from backing out.
11. c. 1.4 mm diameter with a 3 or 4 mm length is the most common optical screw for prescription eyeglass frames.
12. d. Screw on and push on are the two most common types of nose pads.
13. a. The silicone resists slipping, although it may cause a pulling sensation on the nasal skin for some.
14. d. There are multiple ways to utilize silicone nose pads with plastic frames.
15. e. Both of these nose pad types may be replaced with the Logic® replacement nose pad.
16. c. Both crystal and titanium are good materials to use for replacement nose pads when standard nose pad materials cause allergic reactions.
17. a. True.
18. a. True. This may not always be possible, but it is worth a try.
19. a. True.
20. b. False. This may have been the case when rivet hinges were common. Retro-type frame designs are likely to use these for looks only. The hinge is likely to be a standard, imbedded, hidden hinge.
21. b. False. For example, it is not uncommon to combine glue with embedded staples.
22. b. False. Although a Hot Fingers unit makes the task easier, it is not the only method.
23. b. A file may be used to file an eyewire barrel to decrease the circumference of the lens opening.
24. b. False. It may be possible to heat the area and allow it to cool repeatedly in hopes that the compressed area will expand back. If this does not work, there are other more challenging ways to attempt to salvage the frame.
25. c. A cheap, nonpermanent, removable glue that will not damage the lens is recommended.
26. e
27. a. Remember, a lens gap in a new pair of glasses in never acceptable. The prescription needs to be remade.
28. a. True. These lens materials shrink most if they have been previously stretched to fit a slightly larger lens or were stretched too much when initially inserting the lens.
29. b. Ultrasonic cleaning of frames with jewels or similar decorations may cause the jewels to be vibrated loose, causing them to fall out at the time or later.

Chapter 11

1. c. *Centi* means 100, just as there are 100 cents in one dollar.
2. d. Gram. The same prefixes that apply to measures based on the meter apply to grams.
3. c
4. e. Subtracting a negative number results in a positive number.
5. e. $a = \frac{3 \times 7}{4 - 1} = \frac{21}{3} = 7$
6. d. $a = (3 + 7) \times (4 - 2) = 10 \times 2 = 20$
7. d

$$a = \frac{(4 \times 9) + 2}{8} = \frac{36 + 2}{8} = \frac{38}{8} = 4.75$$

8. d

$$5 = \frac{a + 4}{3}$$
$$5 \times 3 = a + 4$$
$$15 - 4 = a$$
$$11 = a$$

9. b

$$7 = \frac{(7 \times 3 + 2)}{a}$$
$$a = \frac{(7 \times 3 + 2)}{7} = \frac{21 + 2}{7} = \frac{23}{7} = 3.29$$

10. b

$$b = \frac{(4 \times a) - 3}{4}$$
$$4b = 4a - 3$$
$$4b + 3 = 4a$$
$$\frac{4b + 3}{4} = a$$

11. a

$$4 = \frac{ab}{(3 + 2b)}$$
$$4(3 + 2b) = ab$$
$$\frac{4(3 + 2b)}{b} = a$$
$$a = \frac{12 + 8b}{b}$$

12. d

$$c = \frac{4b - a}{2b}$$
$$2bc = 4b - a$$
$$a = 4b - 2bc$$

The answer could also be written as

$$a = 2b(2 - c)$$

13. b. This answer $2a^2$ is the same as $2(a \times a)$, which is not the same as $2(a + a)$.
14. e. Change 20 cm to 0.20 m first. Then take the reciprocal, which gives

$$\frac{1}{+0.20} = +5.00\,\text{D}$$

15. d. Change −40 cm to −0.40 m first. Then taken the reciprocal, which gives

$$\frac{1}{-0.40} = -2.50\,\text{D}$$

16. b. Take the reciprocal of −3.00 D, which gives

$$\frac{1}{-3.00\,\text{D}} = -0.333\,\text{m} = -33.3\,\text{cm}$$

17. b

$$I_R = \left[\frac{n' - n}{n' + n}\right]^2 \times I$$
$$I_R = \left[\frac{1.5 - 1}{1.5 + 1}\right]^2 \times 1$$
$$I_R = \left[\frac{0.5}{2.5}\right]^2 \times 1$$
$$I_R = [0.2]^2 \times 1$$
$$I_R = 0.04$$

The amount of light reflected is 0.04, or 4%., of the incident
light.

18. a. 1.22.

$$n_{\text{film}} = \sqrt{n_{\text{lens}}}$$
$$n_{\text{film}} = \sqrt{1.5}$$
$$n_{\text{film}} = 1.22$$

19. c. By similar triangles, 100 is to 200 as x is to 4. Written as an equation this is

$$\frac{100}{200} = \frac{x}{4}$$
$$4 \times \frac{100}{200} = x$$
$$x = \frac{400}{200} = 2$$

20. d. The 1.36-m shadow is to the 1-m tall stick as the 22-m shadow of the telephone pole is to the height (h) of the telephone pole. Expressed as a formula this is

$$\frac{1.36}{1} = \frac{22}{\text{h}}$$
$$1.36\,\text{h} = 22$$
$$h = \frac{22}{1.36} = 16.18\,\text{m}$$

21. d. Use the Pythagorean theorem formula, which is $a^2 + b^2 = c^2$. In this case,. a is how far the bottom of the board is from the wall and equals 0.5 m. The hypotenuse, c, is the length of the board and is equal to 3 m. The height where the top of the board rests against the wall is b. So

$$a^2 + b^2 = c^2$$
$$(0.5)^2 + b^2 = (3)^2$$
$$b^2 = 9 - 0.25 = 8.75$$
$$b = \sqrt{8.75} = 2.96$$

22. a. The two trigonometric functions needed are $\cos\Theta = \frac{\text{adj}}{\text{hyp}}$ and $\sin\Theta = \frac{\text{opp}}{\text{hyp}}$. The angle Θ is the 60-degree angle. The hypotenuse is the 4-m length of the ladder. So the distance from the base of the ladder to the house is the adjacent measure, or

$$\cos 60 = \frac{\text{Adjacent}}{4}$$
$$\text{adj} = 4(\cos 60) = 4(0.5) = 2\,\text{m}$$

The height up the wall where the ladder touches is opposite the 60-degree angle, or

$$\sin 60 = \frac{\text{Opposite}}{4}$$
$$\text{opp} = 4(\sin 60) = 4(0.866) = 3.46\,\text{m}$$

23. b. 4.47Δ.

$$a^2 + b^2 = c^2$$
$$4^2 + 2^2 = c^2$$
$$c^2 = 16 + 4 = 20$$
$$c = \sqrt{20}$$
$$c = 4.47\Delta$$

24. b. 26.57 degrees.

$$\tan\theta = \frac{\text{Opposite}}{\text{Adjacent}}$$
$$\tan\theta = \frac{2}{4} = 0.5$$
$$\theta = \tan^{-1} 0.5$$
$$\theta = 26.57\,\text{degrees}$$

($\tan^{-1}$ stands for the inverse tangent of a number.)

25. c. A parallelogram must have four sides with the two opposite sides parallel to one another. A triangle only has three sides.

Chapter 12

1. d. The angle of incidence and the angle of reflection are the same: 40 degrees. The angle of refraction is found using Snell's law, where

$$n \sin i = n' \sin i'$$
$$1 \sin 40 = 1.33 \sin i'$$
$$\sin i' = \frac{1 \sin 40}{1.33}$$
$$\sin i' = \frac{0.6428}{1.33} = 0.4833$$
$$i' = 29\,\text{degrees}$$

If the sine of the angle i' is known, i' may be found by using the inverse sine ($\sin^{-1}$). Taking the inverse sign of 0.4833 yields 29 degrees.

2. d. When light goes from a denser to a rarer medium, the light bends away from the normal. To find the angle of refraction, we

again use Snell's law. Except we are starting with the higher refractive index.

$$n\sin i = n'\sin i'$$
$$1.33\sin 37 = 1\sin i'$$
$$\sin i' = \frac{1.33\sin 37}{1} = \frac{(1.33)(0.60)}{1} = 0.800$$
$$i' = 53 \text{ degrees}$$

3. c. If the sides of the slab are parallel, no matter how thick the slab, the light will leave the slab with the same angle that it entered the slab.
4. a. $\frac{1}{+0.667\,\text{m}} = +1.50\,\text{D}$
5. b. $\frac{1}{-7.12\,\text{D}} = -0.1404\,\text{m}$
6. b. $\frac{1}{+5.00\,\text{D}} = +0.20\,\text{m} = +20\,\text{cm}$
7. c. $\frac{1}{-0.50\,\text{m}} = -2.00\,\text{D}$
8. b. To find the dioptric power of the surface, use the lensmaker's formula.

$$F = \frac{n' - n}{r}$$
$$F = \frac{1.50 - 1}{+0.08\,\text{m}} = \frac{0.50}{+0.08} = +6.25\,\text{D}$$

9. e. The image point is −4.6 cm from the lens (to the left of the lens).

$$L + F = L'$$
$$\frac{n}{l} + F = \frac{n'}{l'}$$
$$\frac{1}{-0.15\,\text{m}} + (-15.00\,\text{D}) = \frac{1}{l'}$$
$$-6.67\,\text{D} - 15\,\text{D} = \frac{1}{l'}$$
$$l'(-21.67\,\text{D}) = 1$$
$$l' = \frac{1}{-21.67\,\text{D}} = -0.046\,\text{m} = -4.6\,\text{cm}$$

10. d

$$F = \frac{n' - n}{r}$$
$$+3.50 = \frac{n' - 1}{0.20}$$
$$(+3.50)(0.20) = n' - 1$$
$$0.7 + 1 = n'$$
$$n' = 1.7$$

11. c

$$L + F = L'$$
$$\frac{n}{l} + F = \frac{n'}{l'}$$
$$\frac{1}{-0.50} + (-4.00) = \frac{1}{l'}$$
$$-2.00 - 4.00 = \frac{1}{l'}$$
$$l' = \frac{1}{-6.00} = -0.167\,\text{m} = -16.7\,\text{cm}$$

12. a. The object is located +2 m from the lens. This is to the right of (behind) the lens and is therefore a virtual object. Light is converging as it enters the lens.

$$\frac{n}{l} + F = \frac{n'}{l'}$$
$$\frac{1}{l} + 2.50 = \frac{1}{+0.3333\,\text{m}}$$
$$\frac{1}{l} = +3.00 - 2.50 = +0.50$$
$$l = \frac{1}{+0.50\,\text{D}} = +2.00\,\text{m} = +200\,\text{cm}$$

13. b. This lens is a plano cylinder. It could be written as pl +2.00 × 025 or simply +2.00 × 025. The axis meridian of a plano cylinder has zero power. Therefore the +2.00 power is located 90 degrees away from the 25-degree axis meridian. The power median of this lens is in the 115th-degree meridian.
14. b. The front and back surfaces of a plano cylinder are parallel, since the axis meridian has zero power. Light passing through a meridian of zero power is undeviated.
15. d

$$L + F = L'$$
$$\frac{1}{-0.40} - 2.25 = L'$$
$$L' = -2.50 - 2.25 = -4.75$$

16. a. Using the lensmaker's formula, first find the radius of curvature of the surface.

$$F = \frac{n' - n}{r}$$
$$r = \frac{n' - n}{F}$$
$$r = \frac{1.523 - 1}{-5.00} = \frac{0.523}{-5.00} = -0.1046\,\text{m}$$

Once the radius of curvature is found, the lensmaker's formula may be used a second time to find the power of the lens surface in water.

$$F = \frac{n' - n}{r}$$
$$F = \frac{1.523 - 1.333}{-0.1046\,\text{m}} = \frac{0.19}{-0.1046} = -1.82\,\text{D}$$

Note how much the power decreases in water—which explains why wearing regular glasses underwater doesn't always work very well!

17. d. An equiconvex lens has the same plus power on both surfaces and is also biconvex. But a biconvex lens may not have the same power on both surfaces and would then not be an equiconvex lens.
18. e. A meniscus lens has a plus power on one surface and a minus power on the other surface. Both powers do not have to be of equal numeric value as in this example.
19. c. This lens would have a −8.00 D back surface, thus being meniscus.
20. a. The first step is adding the sphere to the cylinder, not subtracting the sphere from cylinder value.
21. b. Add sphere and cylinder together for the new sphere, change the cyl sign, and add 90 degrees to the cylinder axis.
22. d. Place the two meridional powers on a power cross. Consider them as two plano cylinders and write them as such.
23. d. Start with the most plus or least minus power (−1.00). This will be the sphere power. The difference between the two numbers is the cylinder power (3.00 D) and is going in a minus direction from −1.00 to −4.00 and so is given a minus sign.

24. e. To best visualize this, place both plano cylinders on a power cross. Put +1.25 D on the 075-degree meridian and −3.00 D on the 165-degree meridian.
25. b. Take half the cylinder power and add it to the sphere. This would be −0.50 + −6.00 = −6.50 D.
26. a. The entering vergence at the first +5.00 D lens will be −2.50 D. The exiting vergence from the first lens is +2.50 D, coming to a focus at +40 cm to the right of the first lens. This is at a point −40 cm from the second lens. Light will then enter the second lens with a vergence of −2.50 D. It will exit the second +5.00 D lens with a vergence of +2.50 D. The exiting light will focus at a point +40 cm to the right of the second lens.

Chapter 13

1. c. This is a minus cylinder form lens. The base curve is the front sphere curve.
2. a. This is a plus cylinder form lens. The base curve is the weaker of the two front curves.
3. c. The weaker back curve on a minus cylinder form lens is the back, or toric, base curve.
4. a. The front curves are +6.00 and +7.00. The base curve is the weaker of the two curves.
5. b. False. If the lens is a minus cylinder form lens, the front curve is the base curve and the toric, or back, base curve is the weaker of the two curves on the back surface.
6. True. Because of the cost of manufacturing, single-vision lenses used to be made in plus cylinder form. When these constraints were overcome, single-vision lenses were switched to minus cylinder form for consistency with multifocal lenses and cosmetic superiority. That is not to say plus cylinder form lenses are never made or never will be made.
7. b. The front curve is +6.00. Therefore, considering the prescription, if $F_1 + F_2 = F_{\text{Total}}$, then b is the only possible answer.
8. b. If the front surface has no power, the back-surface power will equal the power of the lens. The cylinder power is the difference between the two meridians, or 3.00 D. Taking the prescription from the power cross gives b. If written in minus cylinder form, this would be +1.25 − 3.00 × 067.
9. c. The major meridian powers on the power cross are +1.00 in the 110-degree meridian and +2.00 in the 020-degree meridian.
10. d. Using the Lensmaker's formula in transposed form, $r = \frac{n-1}{F}$, which yields $r = \frac{0.53}{+8.25} = 0.0642\,\text{m} = 64.2\,\text{mm}$.
11. c. Using the lensmaker's formula in transposed form, $r = \frac{n-1}{F}$, which yields $r = \frac{0.74}{+8.25} = 0.0897\,\text{m} = 89.7\,\text{mm}$.
12. b. The base curve as measured with a 1.53 index-referenced lens clock is called the *true base curve*, even though the name is a bit counterintuitive.
13. e. The nominal base curve is 1.53 index-based. However, it is a reference value and is given by the manufacturer. It will be close to the true base curve, but cannot be assumed to be equal to the true base curve.
14. d. The refractive power is calculated from the true base curve using the lensmaker's formula.The true base curve is the lens clock-measured value of +8.17. First the radius of curvature of the surface (r) is found.

$$F = \frac{(n' - n)}{r}$$
$$r = \frac{(n' - n)}{F}$$
$$= \frac{(1.53 - 1)}{8.17} = 0.06487\,\text{m}$$

Now the refractive power of the 1.70 surface is found.

$$F = \frac{(n' - n)}{r}$$
$$= \frac{(1.70 - 1)}{0.06487} = +10.79\,\text{D}$$

15. d. Recognizing that the radius of curvature does not change, the conversion factor for the new material of index 1.67 is determined using $\frac{(1.53-1)}{F_{\text{lm}}} = \frac{(1.67-1)}{F_{\text{nm}}}$. So by transposing, $F_{\text{nm}} = \frac{0.67}{0.53} F_{\text{lm}} = 1.264\,F_{\text{lm}}$.
16. b. False. If the same base curve is always ordered when the prescription changes, the ideal base curve for the new lens power may be missed.
17. True. The curve of a lens affects how shapes and straight lines appear. Two pair of glasses made using different base curves can cause shapes to distort differently. Sensitive individuals may find adaptation more difficult.
18. d. There is a +1.00 D power in one meridian and a −1.00 D power in the other. The difference is 2.00 D, which is the cylinder power.
19. e. The JCC alone has the power of +1.00 − 2.00 × 090 or 180. When a +2.00 sphere is added to it, the answer is +3.00 − 2.00 × 090 or 180.
20. e. First look at the two cylinder components alone. Two cylinders of equal power oriented with axes 90 degrees apart become a sphere lens of that same power (−2.00 D sphere). Now the +2.00 sphere from the first lens is added to that −2.00 sphere resulting from the two cylinder powers. These two cancel, yielding an overall power of zero.
21. b. These two cylinder powers are equal. This means that the new cylinder axis will be halfway between the existing cylinder axes, or 090 degrees. The new cylinder power will be somewhat less than the sum of the two cylinders would be if simply added. Therefore the only possible answer is b.
22. c. The logic is the same as the previous problem. Initially one might think that halfway between axes 015 and 165 is 090 degrees. It is not. Axes 015 and 165 are both closer to axis 180 (or zero) than to axis 090. Remember that axis 165 is the same as axis 345.
23. e. The two cylinder powers are unequal. Therefore the new cylinder axis will not be halfway in between their existing cylinder axis. Instead the new axis is tilted toward the axis of the cylinder with the higher power. It will be between 120 and 130 degrees. (This rules out answers b and d.) Since the cylinder axes are fairly close to one another, the new cylinder power will approach the sum of the two cylinder powers. It will approach but be less than +3.75 D. (This rules out a.) The spherical equivalent of the two original spherocylinders (+6.87 D) must equal the spherical equivalent of the resultant spherocylinder. Response e has this same spherical equivalent.
24. c. The problem may be worked using the graphical or the formula method.
25. c. The problem may be worked using the graphical or the formula method.
26. a. The problem may be worked using the graphical or the formula method. The complete answer for this group of three problems is −3.75 − 1.75 × 035.
27. d. The cylinders cancel and become a sphere of −1.00 D. The two sphere components are added to this and become a −5.50 D sphere.
28. c. The cylinders are equal in power, so the axis is halfway between at axis 045. The axes are almost 90 degrees apart, so the cylinder power goes almost to zero. The only possible answer is c.
29. a. The two cylinder powers are equal, so the axis is halfway between at axis 045. They are very close together, and the cylinder powers sum almost completely. When rounded to the nearest 0.25 diopter,

they do sum to −3.00. Looking at the other answers, it could only be answer a.

30. a. The cylinder powers are unequal, so the resulting axis is closer to the higher powered cylinder's axis. There is only one possible answer that agrees with this.
31. c. All the power is in the 180-degree meridian. The top and bottom edges are equal to the center thickness. If decentered nasally, the longest distance from the optical center to the edge is temporally.
32. b. A plus lens is thickest at the optical center. The edge closest to the center will be the thickest. This is the nasal edge.
33. a. A plano plus cylinder has the same thickness all along the axis of the cylinder. Since it is plus in power, the axis will be the maximum thickness. The 90-degree axis runs top to bottom. Therefore the top and bottom edges are the thickest edges.
34. a. The temporal edge will be thickest since the lens is minus and the decentration is inward. The distance from the optical center to the temporal edge is 25 mm (48/2 + 1) = 25. Using the lensmaker's formula gives a radius of curvature of 0.4873 m, or 487.3 mm. Using the approximate sag formula gives 1.28 mm, or 1.3 mm rounded. So the edge thickness is the sag of 1.3 plus the center thickness of 1.0 to give a 2.3-mm temporal edge thickness.
35. a. On a power cross one can see that the power in the 90-degree meridian is minus, whereas in the 180-degree meridian is plus. So the lens thins toward the edge in the 180-degree meridian and thickens toward the edge in the 90-degree meridian, making the top and bottom the thickest edges.
36. d. The accurate sag formula gives answer d exactly. The approximate sag formula gives an answer of 3.29 mm, which is closer to answer d than any other response.
37. e. The ED is 56. The constant (K) is 1.0 for a 58-mm ED, so we will assume a constant of 0.9. Therefore, ET = (0.9 × 9) + 2.0 = 10.1 mm.
38. d. The rule of thumb estimates an increase of half the value of the prescribed prism in millimeters. Therefore the increase in thickness is 1.5 mm.

Chapter 14

1. c. The focal point of a +8.00 D lens is +12.5 cm to the right of the lens. The reference plane is 2.5 cm to the right of the lens. The distance from the reference plane to the focal point is +10 cm. Therefore the vergence of light at that reference plane is $\frac{1}{0.10\,\text{m}} = +10.00\,\text{D}$.
2. d. The focal point of −8.00 D is −12.5 cm to the left of the lens. The reference plane is 2.5 cm to the right of the lens. The distance from the reference plane to the focal point is −15 cm. Therefore the vergence of light at that reference plane is $\frac{1}{-0.15\,\text{m}} = -6.67\,\text{D}$.
3. d. The compensated power of a plus lens must be stronger if it will be closer to the eye than the originally refracted lens location.
4. b. The compensated power of a minus lens must be weaker if it will be closer to the eye than the originally refracted lens location.
5. b. The contact lens power would be less because the distance from the correcting lens to the far point of the eye, where the second principal focal point of the correcting lens must be located, is greater for a contact lens than for a spectacle lens.
6. d. Because the lens is plus and the vertex distance is shorter, the lens power must be higher.
7. b. The nonrounded major meridional powers of the compensated lens are −8.96 D and −11.98 D. The unrounded cylinder power would be 3.02 D.
8. e

$$\text{Reduced thickness} = \frac{t}{n} = \frac{10\,\text{mm}}{1.67} = 6.0\,\text{mm}$$

9. d. A lensmeter normally measures the back vertex power. If the glasses are turned around, the front vertex power is being measured.
10. b. If parallel light enters a plus-powered front surface, the front curve will increase the vergence of the entering light. Then as light travels through the lens, vergence increases and so the back vertex power will increase. If parallel light were to enter the plano back surface, vergence would be unchanged until it reached the front surface. The front vertex power would equal the power of the front surface of the lens.
11. a. Notice the difference of 0.11 D between the approximate and accurate formulas for finding the back vertex power of this lens.
12. a. No matter which method is used, the answer is always +7.00 D. This is because the back of the lens is almost plano. Therefore, there is very little vergence change as parallel light travels right to left through the low-powered back lens surface.
13. c. If the front surface has plus power and the lens is thick, the back vertex power is always stronger than the nominal power of the lens.
14. e. To find the answer, it is possible to either use vergences or to use the back vertex power formula. If using the formula, substitute +2.00 D for F_v' and solve for F_2 as the unknown.
15. b. When light is refracted at the first surface of a thick lens, the higher the surface power, the more gain there is in power by the time it reaches the second surface. So the higher powered meridian will pick up more power as it travels through the lens than the lower powered meridian. Therefore, the difference in front surface meridian powers would need to be reduced below the actual cylinder power so that a correct back vertex cylinder power is possible.

Chapter 15

1. a. This problem uses the formula of $d = a(n - 1)$ for thin prisms.
2. b. Since the index is 1.5, the formula for thin prism is even simpler, reducing down to $d = a/2$. This means that if the index is 1.5, the angle of deviation may be found just by dividing the apical angle by 2.
3. d. The answer is found by transposing the formula $d = a(n - 1)$ so that n is the unknown.
4. b. The eye will turn in the direction that the apex of the prism points. The base is to the right and the apex to the left. So the eye turns to the left.
5. c. The formula $\tan d = \frac{P}{100}$ is used to convert degrees of deviation into prism diopters. The tangent of 1.5 degrees is 0.026, which, when multiplied by 100, results in 2.6 prism diopters.
6. a. Light is deviated in the direction of the base of a prism in air. This means that the image of an object seen through the prism is displaced toward the apex.
7. d. The answer is found by using the formula $\tan d = \frac{P}{100}$.
8. b. Remember, the image of the object will appear displaced in the direction that the apex of the prism points—opposite from the prism base direction.
9. b. The answer is found by first knowing that, at 1 m, the image of an object is displaced by an amount equal to the dioptric value of the prism. Then the answer may be found for a different distance by using similar triangles.
10. c. By similar triangles, 6 is to 1 as x is to 6. In other words, $\frac{6}{1} = \frac{x}{6}$, so $x = 36$.
11. c. The answer is found by using the definition of a prism diopter and similar triangles.

12. e. Using the definition of a prism diopter, the power of a prism may be found by dividing the object distance in meters by the distance the image is displaced in centimeters. In this case the prism amount is $\frac{1.75\text{ m}}{1.75\text{ cm}} = 1.00\Delta$.
13. c. This is a problem that, again, uses the definition of a prism diopter and similar triangles to find the correct answer.
14. b. Prism centrads deviate light more per unit than prism diopters, with the difference increasing with increasing prism power.
15. c. Base left could be either base in or base out, depending upon which eye is referenced. For the right eye this must be base in.
16. d. Here we see that the correct answer is base out—in contrast to that of the previous problem.
17. a. For the right eye, base in has the base to the right. When written in the polar coordinate system of degrees, base zero is always to the observer's right.
18. $3^2 + 1.5^2 = \sqrt{9 + 2.25}$
$= \sqrt{11.25}$
$= 3.35$
The base direction can be found from
$$\tan\theta = \frac{3.00}{1.50} = 2$$
$$\theta = \text{Inverse tangent of } 2$$
so
$$\theta = 63 \text{ degrees}$$
The final base direction will be 63 + 90 = 153 degrees.
19. c. We know the base must be greater than 180 because of the base-down component. Because of the base-in component of a left eye, the base direction is further narrowed down to between 180 and 270. Even though there is only one prism amount given, be certain you can accurately find that prism amount.
20. b. Because the vertical prism is up, the answer must be between zero and 180. Since the horizontal is base in for the left lens, the answer can be further narrowed do to between 90 and 180. Even though there is only one prism amount given, be certain you can accurately find that prism amount.
21. d. For the right eye, base 330 would indicate an inward and downward direction, so the only possible answer would be d. Even though the answer is already given, be able to find the horizontal and vertical prism amounts using trigonometry.
22. b. False. Base-out prism before the left eye gives the opposite binocular prismatic effect as base-in prism before the right eye.
23. a. True. Prism may be split equally—or even unequally—between right and left eyes. Base in before the right eye gives the same binocular effect as base in before the left eye.
24. b. False. Base-up prism before the left eye is the opposite binocular prismatic effect as base-up prism before the right eye.
25. c. Base 180 before the right eye is the same as base out. Base out before the right eye is the same as base out before the left eye. Base out before the left eye is the same as base 000.
26. d. Answer d shows 2 base up on the left lens. This is opposite from all the other possible answers.
27. b. Since the lens is a left lens, base 150 would indicate base in. Since the degree measurement is closer to the horizontal meridian than the vertical meridian, the horizontal prism would have more power than the vertical prism.
28. d. $\tan\theta = \frac{3}{4} = 0.75$. The inverse tan of 0.75 is 37 degrees. However, one must consider that because this is for the left eye, the base direction will be 180 − 37, or 143.
29. b. For the right eye, the base direction is above the 180. So the vertical component will be up. At 45 degrees, the horizontal component will be in the first quadrant. For the right eye this will be toward the nose, or in. Had it been for the left eye the horizontal component would have been out.
30. b. The resultant horizontal prism components cancel one another out (equal base-in and base-out amounts) and the vertical prism components (both being base up) are additive.
31. a. For the first oblique prism, the results are 2.00Δ base up and 1.50Δ base out. For the second oblique prism the results are 1.50Δ base down and 2.00Δ base in. Adding vertical prism components results in 1.00Δ base down added to 1.50Δ base up. This yields 0.50Δ base up. Adding horizontal prism components results in 1.50Δ base out added to 2.00Δ base in. This yields 0.50Δ base in. These two equal-powered prisms 90 degrees away from one another may be combined. The axis is midway between the two at 135 with the prism amount of 0.71Δ.
32. d. As the bases of the prism move upward or downward, the resultant horizontal prism components are equal and opposite, canceling each other out. The vertical prism components are both in the same direction, increasing as the two prisms rotate.
33. c. The only feasible answer is 5.25Δ. If the object is closer than infinity, the effective prism power will be less than the marked power of the prism. The 5.25Δ effective prism power is the only answer that qualifies.
34. a. The effective power of a prism at near must be less than the actual power of the prism, so a is the only possible answer.
35. d. Answers a and b can be ruled out as effective prism power is less at near. Answer c is too close to the actual prism power. This makes answer d the only feasible answer.

Chapter 16

1. c. A plus lens decentered inward gives base in. Use Prentice's rule for prism amount.
2. d. If the lens is moved upward and the prism created is base down, the lens must be minus in power.
$$F = \frac{\Delta}{c} = \frac{2.10}{0.3} = 7.00\text{ D}$$
3. a. If the optical center of a minus lens moves outward, the prism base direction produced will be opposite, or inward.
4. d. The power in the vertical meridian is −1.00 D. To produce base-up prism, the minus lens must move downward. Decentration is
$$c = \frac{\Delta}{F} = \frac{1}{1} = 1\text{ cm or } 10\text{ mm}$$
5. e. If the optical center of a minus lens is moved outward, the prism induced will be inward. The amount will be $\Delta = cF = (0.8)(4.00) = 3.20\Delta$. To the nearest 0.25 prism diopter, this is 3.25Δ.
6. d. The optical centers are inward relative to the position of the eyes. For a minus lens, if the centers move inward, the base direction is opposite, or outward. The prism amount is
$$\Delta = cF = (0.7)(6.25) = 4.375$$
7. d. The optical centers are inward relative to the position of the eyes. For a minus lens, if the centers move inward, the base direction is opposite, or outward. For the right eye the prism amount is
$$\Delta = cF = (0.2)(5.00) = 1.00$$

For the left eye the prism amount is

$$\Delta = cF = (0.2)(8.00) = 1.60$$

The total amount of prism is 2.60Δ base out.

8. d. The optical centers are outward relative to the position of the eyes. For a plus lens power, if the centers move outward, the base direction is the same, or outward. The power in the 180-degree meridian is +2.75 D for both right and left eyes. The cylinder has no power in the 180-degree axis meridian. In total, the PD is off 10 mm. Therefore, total the prism amount is

$$\Delta = cF = (1.0)(2.75) = 2.75$$

9. e. The optical centers are outward relative to the position of the eyes. For a minus lens power, if the centers move outward, the base direction is opposite, or base in. The power in the 180-degree meridian for the right eye is −2.00 D. For the left eye the power in the 180-degree meridian is −4.00 D. Therefore, the prism amount for the right eye is $\Delta = cF = (0.4)(2.00) = 0.80$.

   For the left eye, the prism amount is $\Delta = cF = (0.4)(4.00) = 1.60$.

   The total binocular prismatic effect is 2.40Δ base in.

10. b. The optical centers are outward relative to the position of the eyes. For a minus lens power, if the centers move outward, the base direction is opposite, or base in. The power in the 180-degree meridian for the right eye is −4.50 D. For the left eye the power in the 180-degree meridian is −7.00 D. Therefore, the prism amount for the right eye is $\Delta = cF = (0.2)(4.50) = 0.90$.

    For the left eye, the prism amount is $\Delta = cF = (0.2)(7.00) = 1.40$.

    The total binocular prismatic effect is 2.30Δ base in.

11. b. The PD is off by more than 2.5 mm. The prismatic effect caused by the misplaced optical centers may be calculated using Prentice's rule and is found to be causing 1.20Δ of total base-in prism. This is more than the 0.67Δ tolerance amount. The pair fails on both counts and thus fails ANSI standards.

12. c. Remember that in the lensmeter, the target indicates the base direction. (What you see is what you get.) The base direction starts out with a base-down prismatic effect. When the axis of the cylinder crosses the lensmeter aperture, the base shifts to base up and the target moves in an upward direction.

13. b. The prism base direction has only two possibilities: base 135 (up and out) or base 315 (down and in). Since the wearer (or lensmeter) is looking through a point to the right of the axis, the base direction is 315 (down and in).

14. a. Base in. The lens optical center is inward from the location of the blank geometric center. Therefore the base direction at the blank geometric center is base in.

15. b. Base out and up. The base direction to the left of the minus cylinder axis is base 130. Because this is a right lens, base 130 will have a base-out horizontal component and a base-up vertical component.

16. c. Base in and down. The base direction to the left of the plus cylinder axis is base 310. Because this is a right lens, base 310 will have a base-out horizontal component and a base-up vertical component. The plus sphere will contribute base-in prism as well.

17. a. Base in and up. The base direction to the left of the minus cylinder axis is base 130. Because this is a right lens, base 130 will have a base-out horizontal component and a base-up vertical component. However, the sphere component is four times as strong as the cylinder lens and the sphere is causing only base-in prism. This overpowers the smaller amount of base-out prism caused by the cylinder, resulting in on overall effect of base up and base in.

18. a. The lens has a power of −5.00 D in the horizontal meridian. Therefore $\Delta = cF$. So

$$c = \frac{\Delta}{F} = \frac{3.00}{5.00} = 0.6\,\text{cm} = 6\,\text{mm}$$

Since the prescribed prism at the MRP (or PRP) is base in, we know that for a minus lens the optical center (the thinnest part of the lens) will be found temporally.

19. d. You do not need to do any calculations to get the correct answer!

    For vertical prism:

    The two cylinders have exactly the same powers and the axes are mirror images of each other. This means that even if the PD is off horizontally, both will induce the same amount of vertical prism in the same base direction. (Both induce 0.14Δ of base-down prism.) Besides being less than 0.33 prism diopter, since both are in the same direction, this results in a net vertical prismatic effect of zero.

    For horizontal prism:

    There is almost no horizontal prismatic effect because the plano cylinder axes are both close to 180. There is no refractive power along the cylinder axis. The exact amount of horizontal prism is only 0.037Δ base in for each eye, for a total of 0.074Δ binocularly. This is clearly well below the 0.66 prism diopter tolerance allowed.

20. c. The effective decentration (d_e) can be found by trigonometry as shown here, or it can be simply drawn to scale and measured. Although not as accurate when measured, a scale drawing will still give acceptable results.

$$\sin 75 = \frac{\text{opp}}{\text{hyp}} = \frac{d_e}{5\,\text{mm}}$$
$$d_e = 5(0.966) = 4.83\,\text{mm}$$

Next the prism amount is found.

$$\Delta = cF = 0.483(3.50) = 1.67\Delta$$

The base direction is 75 + 90 = 165, resulting in 1.67Δ base 165.

This answer expressed in degrees is next changed into horizontal and vertical components. If this is drawn to scale, the vertical and horizontal components may also be measured. Note that this will be a new drawing. It is not a part of the scale drawing used to find d_e. To find the vertical component:

$$\sin 15 = \frac{V}{1.67}$$
$$V = 0.2588 \times 1.67 = 0.43\Delta$$

To find the horizontal component:

$$\cos 15 = \frac{H}{1.67}$$
$$H = 0.966 \times 1.67 = 1.61\Delta$$

For the right eye, a base direction of 165 is up and out, making the answer 0.43Δ base up and 1.61Δ base out.

21. b

$$P = \frac{100g(n-1)}{d}$$
$$= \frac{100(1)(0.8)}{54} = 1.48\Delta$$

22. c

$$P = \frac{100g(n-1)}{d}$$
$$= \frac{100(7.8-5.4)(1.66-1)}{40}$$
$$= \frac{100(2.4)(0.66)}{40}$$
$$= 3.96\Delta \text{base } 180 (\text{base out})$$

23. a

$$P = \frac{100g(n-1)}{d}$$
$$P = \frac{100(0.5)(0.5)}{50} = 0.50\Delta$$

24. c. Because base-out prism will thin a plus lens, you want more base out on the higher plus lens.
25. b. Base-in prism on a plus lens decentered inward will maximally increase the lens center thickness. This is because all of the thickness of the prism base is added to the nasal side of the lens. The nasal side is already the thickest part of the lens, even before the prism is added.

Chapter 17

1. b. The orientation of the Fresnel prism lines is always 90 degrees away from the prism base direction.
2. b. The lines are always 90 degrees away from the base-apex line of the prism. The lines would be in the 135/315-degree meridian. Make sure the base direction is 45 and not 225. In both cases the lines will be in the 135/315-degree meridian.
3. b. There is a slight decrease in visual acuity for both conventional prisms and Fresnel prisms. However, the reflections at the prism facets of the Fresnel prism will cause a further slight amount of reduction in visual acuity, giving the conventional prism a slight visual acuity advantage.
4. b. False. Conventional prism can reduce visual acuity because of chromatic aberration and prism distortion.
5. c. Because both Fresnel lenses and prisms can be peeled off the carrier, they are both reusable.
6. a. Remember bb, or base blind, to quickly remember the correct base direction.
7. e. Both unilateral and yoked sector prism used for homonymous hemianopia will create an apical scotoma. Unilateral sector prism will also show diplopia in the central viewing area.
8. b. The objects in the central section of the nonseeing area are shifted into the areas occupied by the segment prisms. This may make it feasible for the person with homonymous hemianopia to drive using this type of peripheral prism.
9. d. Turning the head to the left means the eyes will be turned right, slowing the nystagmus. Prism base left will cause the eyes to turn right, in the direction of the apex. Now the person can keep the head facing forward while turning the eyes right.
10. c. The back application is more protected, and the smooth side is able to adhere through capillary action.
11. c. Water between the carrier and the Fresnel prism causes the two to adhere through capillary action.

Chapter 18

1. b

$$\text{Lateral chromatic aberration} = \frac{\Delta}{\nu}$$
$$= \frac{1.5 \times 7.00}{30} = 0.35\Delta$$

2. b. False. Visual acuity will decrease with an increase in the amount of prism. If the lens has significant refractive power, the amount of prism in the periphery of the lens will increase according to Prentice's rule. This could cause enough of a prismatic effect for enough in the periphery to have a noticeable effect on visual acuity.
3. c. Prism affects visual acuity even if there is no sphere or cylinder refractive power.
4. c. When prism reduces visual acuity, it doesn't matter if it is induced from viewing through an off-axis point of a powered lens or if the prescription contains only prism.
5. b. The lower the Abbé value, the higher the chromatic aberration. A 22 value is low.
6. b. CR-39 plastic and crown glass have very high Abbé values, signifying low chromatic aberration.
7. b. An AR coating may improve wearer satisfaction but not because it reduces chromatic aberration. It does not reduce chromatic aberration.
8. b. Achromatic lenses are not used for spectacle lenses.
9. c. A point focal lens corrects for unwanted oblique astigmatism. When the lens is corrected for the anticipated object distance and desired degrees from the optic axis of the lens, the peripheral object point will come to a specific focal point with no unwanted oblique astigmatism.
10. b. Tscherning ellipse size will vary with working distance, so answer a. is incorrect. Except at the extreme ends of the ellipse, there are two lens forms that will correct for oblique astigmatism, so c is also incorrect.
11. c. When a lens is tilted, the new induced sphere power will be greater than the old sphere power.
12. b. The new induced cylinder will have the same sign as the sign of the lens being tilted.
13. a. Even though counterintuitive, lens power does not influence induced prism from wraparound.
14. d. Remember that with lens wraparound, lens power does not influence induced prism.
15. c. A minus lens causes barrel distortion and minifies the image.
16. d. Correct curve (best form) lenses may use any of the philosophies in a, b, or c. However, option c is almost always used.
17. d. Just looking at the possibilities, answer d should be the most logical. We can use Vogel's formula, which gives:

$$\text{Base curve}_{(\text{minus lenses})} = \frac{\text{Spherical equivalent}}{2} + 6.00\,\text{D}$$
$$= \frac{-10.00}{2} + 6.00$$
$$= -5.00 + 6.00 = +1.00$$

18. d

$$\text{Base curve}_{(\text{minus lenses})} = \frac{\text{Spherical equivalent}}{2} + 6.00\,\text{D}$$
$$= \frac{-1.00 + \frac{-2.00}{2}}{2} + 6.00$$
$$= +5.00$$

19. b. As plus lens power increases, the back surface becomes progressively flatter, while the front curve becomes steeper.
20. a. A zero-powered lens usually has a +6.00 D base curve. As plus lens power increases, the front curve of the lens becomes steeper. As minus power increases, the base curve flattens.
21. a. The beauty of aspheric optics is that it allows a lens of a certain power to be decoupled from the otherwise-needed base curve as long as the asphericity is designed appropriately.

22. d. The visual acuity through the center of a spherically based lens is just as good as that of an aspheric lens of the same power when viewing through the center.
23. c
24. b. The higher the minus lens power and the larger the bowl diameter, the thicker the carrier of a true myodisc lens will be.
25. b. A lenticular design does not necessarily come with an aspheric central or aperture portion.
26. b. Although the thickness of a regular plus-powered lens surfaced for optimum thickness will vary with frame ED and decentration, a plus-powered lenticular lens thickness is already made as thin as possible because of its design.
27. b. Outcomes resulting from under correcting a progressing myope are worse than when the full myopic correction is prescribed.
28. a

Chapter 19

1. b. Near power is the total of the distance power plus the near addition.
2. e. Seg depth is the longest vertical dimension of the multifocal segment before the lens has been edged. The seg height is the measured vertical distance from the top of the segmented multifocal to the lowest level of the inside bevel of the frame. There is not a predictable relationship between the two.
3. b. -1 mm + 2.5 mm = 1.5 mm
4. e. The near add is the difference in power between distance and near lens powers.
5. c

$$\frac{\text{Intermediate add}}{\text{Near add}} = \frac{+1.50}{+2.50} = 0.60 \text{ or } 60\%$$

6. a. A fused glass multifocal segment has the same curvature as the rest of the front surface of the lens. All the others change in curvature and because of that change in curvature can be felt by running one's fingers over the lens surface.
7. b. The Executive lens is made from one lens material.
8. a. Fused glass segmented multifocal lenses are made so that the increase in add power is a result of a segment portion of higher index of refraction than the rest of the lens.
9. b. Glass lenses can also be made to have a different segment power as a result of a change in lens surface curvature.
10. d. Seg drop is equal to the difference between half the B dimension and the seg height.
11. b. The segment optical center is 11 mm, or 1.1 cm, below the top of the segment.

$$\Delta = cF_a = (1.1)(2.00) = 2.20\Delta$$

12. a. Notice that the only two factors needed are how far the seg optical center is below the seg top and the power of the near addition.

$$\Delta = cF_a = (0.5)(2.50) = 1.25\Delta$$

13. d. The segment optical center of an Executive bifocal is on the bifocal line, so there is no image jump.
14. e. The power of the reading glasses is the sum of the distance power and the near addition. The cylinder power of the distance lens is always included in reading glasses.
15. d. Fifty percent of a +2.50 add is +1.25. This amount is added to the distance portion. The near portion must still remain the same power as previously. That means only +1.25 additional power—add power—is needed.
16. b. Hyperopes accommodate more in spectacle lenses than emmetropes or contact lens wearers.
17. c. The high cylinder, especially in combination with a high sphere component, means that a different stimulus to accommodation occurs in each of the major meridians, leaving uncorrected cylinder at near. Initially one might think that answer d is correct, as both spheres and cylinders are higher. However, as add power increases, this difference in stimulus to accommodation decreases. The glasses in *d* have almost a full add power for the customary 40-cm working distance.
18. d. A myope does not need to accommodate as much in spectacle lenses. Having refractive surgery is optically the same as wearing contact lenses, returning the eye to emmetropia. So this person will have to accommodate more, requiring a higher reading addition. She is likely to be disappointed if she thinks she won't need to wear glasses anymore.
19. c

$$c_a = \frac{\text{Near prism}}{F_a} = \frac{0.75}{2.00} = 0.375 \text{ cm} \cong 3.8 \text{ mm}$$

20. c

$$\begin{aligned}\text{Net seg inset} &= \text{Seg inset} + \text{Additional seg inset}\\ &= \frac{66-62}{2} + \frac{1.50}{2}\\ &= 2 \text{ mm} + 0.75 \text{ cm}\\ &= 2 \text{ mm} + 7.5 \text{ mm}\\ &= 9.5 \text{ mm}\end{aligned}$$

21. c

$$\begin{aligned}\text{Seg size} &= 2(10 + \text{Additional seg inset})\\ &= 2\left(10 + \frac{1.50}{2.00}\right)\\ &= 2(10 \text{ mm} + 0.75 \text{ cm})\\ &= 2(10 \text{ mm} + 7.5 \text{ mm})\\ &= 35 \text{ mm}\end{aligned}$$

22. a. Add powers are plus in power. Decentering a plus lens creates prism in the same base direction as its decentration.
23. b

$$\begin{aligned}\text{"Near PD"} &= \text{Distance } PD - 2(\text{Net seg inset})\\ &= 65 - 2(\text{Seg inset} + \text{Additional seg inset})\\ &= 65 \text{ mm} - 2(1.5 \text{ mm} + 0.89 \text{ cm})\\ &= 65 \text{ mm} - 2(1.5 \text{ mm} + 8.9 \text{ mm})\\ &= 65 \text{ mm} - 2(10.4) \text{ mm}\\ &= 65 \text{ mm} - 20.8 \text{ mm}\\ &= 44.2 \text{ mm} \cong 44 \text{ mm}\end{aligned}$$

24. d

$$\begin{aligned}\text{Seg size} &= 2(10 + \text{Additional seg inset})\\ &= 2(10 + 8.9)\\ &\cong 38 \text{ mm}\end{aligned}$$

25. c

$$\begin{aligned}\text{Net seg inset} &= \text{Seg inset} + \text{Additional seg inset}\\ &= 1.5\,\text{mm} - 1.25\,\text{cm}\\ &= 1.5\,\text{mm} - 12.5\,\text{mm}\\ &= -11\,\text{mm}\end{aligned}$$

Because the prism is base out at near instead of base in, the additional seg inset is really an outset. For these purposes it is the same as a negative additional seg inset.

26. d

$$\begin{aligned}\text{Seg size} &= 2(10 + \text{Additional seg inset or outset})\\ &= 2(10 + 12.5)\\ &= 45\,\text{mm}\end{aligned}$$

Even though the additional seg inset is actually an outset, since the additional seg decentration (inset or outset) begins at the reading position, it is taken as an absolute value and is added to 10 mm.

27. a. There will be a change in the prismatic effect. Prismatic effect will change because of the add being decentered, even if the refractive powers of distance and near neutralize out. Prismatic effect will manifest, even without dioptric (D) refractive power. Consider the plano prism that has no dioptric refractive power—only prism (Δ) power.

Chapter 20

1. e. Rotation of the progressive channel is no longer required with current progressive lens designs.
2. c. Since the existing left lens has a fitting cross height that is 1 mm higher than you measured, to maintain relative fitting height, the right lens height ordered should also be 1 mm higher than you measured. 20 mm + 1 mm = 21 mm. (**NOTE:** This same relative fitting height procedure is also used for segmented multifocal heights.)
3. e. If progressive lenses are fit on children 7 years of age or younger who are still able to accommodate, the fitting cross should be raised to assure that the near addition portion is being used for near work.
4. b. Fitting a progressive addition fitting cross low will cause the progressive zone to misalign. The eyes will not track down the center of the progressive corridor properly.
5. a. Prism is verified at the PRP, which is where the progressive lens begins to change in power. Thus the distance power must be verified higher in the lens for accuracy—even above the location of the fitting cross.
6. b. The fitting cross is above the PRP. The PRP and MRP are synonymous.
7. a. Most progressive lens designs are multidesigns. The near viewing needs of the wearer change as add power increases.
8. a. Even choosing a high-end progressive lens in an appropriate lens material will not overcome problems caused by inaccurate facial measurements and/or a frame that is inappropriately adjusted for a progressive addition lens.
9. a. Most of the time the add power is read using the semivisible markings on the lens.
10. a. There are several appropriate methods to enable the semivisible lens markings to be seen, but using a mirror is not one of them.
11. c. Binocular PDs are inappropriate—monocular PDs are needed. An aviator lens shape cuts away a good portion of the near viewing zone of the lens. A 12-degree pantoscopic angle is usually close to the correct amount of tilt for a progressive addition lens.
12. a. Seeing where the primary points of the lens are located in reference to the eye and lens shape will quickly reveal where several potential possibilities for error are located.
13. d. Fitting accuracy is more important than the brand of progressive addition lens selected. No brand of progressive addition lens is able to overcome a poor fitting.
14. b. Unwanted peripheral cylinder increases both with add power and near zone width.
15. a. The nature of a soft design is to spread the unwanted peripheral aberration over a larger area of the lens. This reduces the power of the unwanted cylinder but allows it to encroach into the distance peripheral area of the lens.
16. c. A rapid change in power from distance to near viewing results in a shorter progressive corridor and allows for a wider near viewing zone.
17. a. Distance, intermediate, and near sizes for progressive addition lenses all affect each other.
18. d. Chromatic aberration is affected by the Abbé value and power of a lens and is not related to progressive addition lens contour plots.
19. a. A short frame B dimension reduces the progressive corridor length and increases the near zone width. Since this increases the amount of peripheral aberration, the amount of unwanted peripheral cylinder increases rapidly at the borders of the progressive corridor. This is an indicator of a hard progressive lens design.
20. b. Distance vision for an emmetrope has always been clear. A soft design puts some unwanted cylinder in the upper periphery of a lens. This area has always been clear before. These glasses make distance vision in the periphery worse, which could lead to complaints.
21. e. Progressives made as semifinished lenses are the traditional way progressives were made and do not require free-form generating.
22. e. Position-of-wear lenses take all of the above into consideration in assuring that the lenses in the glasses will deliver the intended prescription shown in the prescribed lenses.
23. b. The upper portion of a degressive lens will have a percentage of the add power that varies according to the intended working distances of the lens.
24. b. Note that the terms *near variable focus lens* and *degressive lens* are synonymous.
25. b. Add the near addition to find the total near power, which will be +3.00 − 0.75 × 090. Subtract the power range (degression) of 1.25 from the total near power to get the power at the top of the lens, which is +1.75 − 0.75 × 090.
26. c. The difference in the sphere powers between the top and bottom of the lens is +2.75 minus a +1.25, which is 1.50 D.
27. b. There are occupational progressive lenses made with a small portion at the top of the lens for distance vision. They are still useful for computers and small office environments because their long progressive corridor allows for wider intermediate and near portions.
28. d. Two-thirds of the add power is 1.50.
29. b. 0.3 mm times the prism amount of 3Δ equals 0.9 mm, which is rounded up to 1 mm. For the right eye the base direction is down, so the image will be displaced upward. The fitting cross would be move upward from 20 to 21 mm. The same calculation is applied to the left eye, but the base direction is up, so the fitting cross would be move downward from 20 to 19 mm.
30. c. For the right lens, 5 times 0.3 mm equals 1.5 mm. The base is in, so the monocular PD is increased by 1.5 mm, resulting in 31 mm. For the left lens, 3 times 0.3 mm equals 0.9 mm, which rounds up to 1.0 mm. Again, the base is inward, so the monocular PD is increased from 30.5 to 31.5 mm. It should be noted that the amount of prescribed prism does not need to be changed because, even though the total prism is above 6Δ, the refractive power in the meridian of movement is less than 2.50 D.

31. b. To find the change in prescribed prism, use Prentice's rule ($\Delta = cF$). Multiply the change in the monocular PD in centimeters times the distance lens power in the meridian of movement (the 180-degree meridian). This is

$$\begin{aligned}\Delta &= cF\\ &= 0.1 \times 5.00\\ &= 0.5\Delta\end{aligned}$$

Because the lens is a minus lens, the change in prism amount is subtracted from the previous amount prescribed to find the needed new amount of prescribed prism.

$$3.0\Delta - 0.5\Delta = 2.5\Delta \text{ Base in}$$

Since right and left lenses are the same, the new amount is the same for both eyes.

32. d. Only *d* requires prescribed prism to be compensated. Although many have the total prism amount above 6Δ, only d has the power in the 180-degree meridian greater than or equal to plus or minus 2.50 D. Place the powers on a power cross to see what the power in the 180-degree meridian for each of the lenses proves to be.

Chapter 21

1. e. Physiological aniseikonia is the slight difference in image sizes that occurs when, even though both eyes have the same amount of refractive error (or none at all), the image in one eye will be slightly larger or smaller than the other.
2. c. Spectacle magnification (SM) is equal to:

$$\begin{aligned}SM &= \left(\frac{1}{1-\frac{t}{n}F_1}\right)\left(\frac{1}{1-hF'_v}\right)\\ &= \left(\frac{1}{1-\frac{0.0043}{1.498}(8.50)}\right)\left(\frac{1}{1-(0.016)(3.00)}\right)\\ &= \left(\frac{1}{1-0.0244}\right)\left(\frac{1}{1-(0.048)}\right)\\ &= \left(\frac{1}{0.9756}\right)\left(\frac{1}{0.9520}\right)\\ &= (1.0250)(1.0504)\\ &= 1.0767 \text{ or } 7.67\%\end{aligned}$$

3. a. True. Spectacle magnification compares the size of the image seen by a person when wearing glasses with the size of the image seen when that same individual is not wearing glasses. Relative spectacle magnification compares an ametropic but corrected eye with a standard emmetropic eye that does not need a correction.
4. c. The distance from the lens back surface to the entrance pupil of the eye is closely related to vertex distance, which is part of what gives the lens its working power.
5. b. In spite of what Knapp's law says, aniseikonia is still present when axial ametropia is corrected with regular spectacle lenses.
6. a. Because this statement is true, aniseikonia may be overlooked because of the similarity of symptoms caused by other common refractive problems.
7. c. Although steepening base curves may change magnification, simply doing so for both lenses does not insure that those lens magnifications will move closer to one another.
8. b. The higher plus lens is already the lens with the greater magnification. Steepening the base curve of the higher plus lens will increase its magnification even more.
9. d. Reducing vertex distance will decrease both the magnification of the plus lens and the minification of the minus lens, moving the image sizes closer to one another. Decreasing vertex distance to zero would be the same as using contact lenses, which would be the best choice from the standpoint of reducing aniseikonia.
10. b. 1.0% magnification difference. It should be noted that the percentage difference estimated or even measured clinically may not necessarily be the same as the calculated magnification differences between left and right.
11. d. Achiron et al.[6] found that, at the conclusion of their study, 93% of the study subjects preferred the spectacles that had been modified to correct for aniseikonia over traditional spectacles.
12. c. By placing two curves on the front and two curves on the back, it is possible to reduce aniseikonic differences between the two eyes even when those differences are not the same in the two meridians tested.
13. b. Often individuals with longstanding aniseikonia are able to adapt to magnification differences over time. A sudden change in magnification differences cannot be easily overcome.
14. a. Vertical prismatic imbalance is a spectacle-lens–induced problem.
15. b. Because the wearer is able to look through the optical centers to view distant objects with one pair of glasses and near objects with the other, no vertical imbalance is created for either of these two primary viewing areas.
16. b. False. Often subjective symptoms caused by vertical imbalance can be alleviated by reducing the imbalance, even though some imbalance remains. So even though the easiest choice may be to order the full calculated amount, this might not always be the best choice.
17. d. Traditional slab-off prism is base up in direction. Therefore, it is ground on the most minus to counteract some of the greater amount base down from that stronger minus lens. When lenses are plus, it is ground on the least plus to balance out the stronger base up on the other, stronger-powered plus lens.
18. b. The eye care practitioner can take several factors into consideration when ordering slab-off prism. However, an experienced optical laboratory should be able to calculate the full amount of vertical imbalance if requested to do so. The eye care practitioner has ultimate responsibility and must have confidence that what is being asked of the laboratory can be accurately carried out.
19. b. The power in the 90-degree meridian for the right lens is −3.50 D and for the left lens is −5.50 D. (The cylinders have no power in the 90-degree meridian.) The difference in powers is 2.00 D. The amount of imbalance is

$$\Delta = cF = 1.0 \times 2.00 = 2.00$$

The slab off goes on the most minus or least plus in the 90-degree meridian, which is the left lens (O.S.).

20. b. All the power from the right lens minus cylinder component is in the 90-degree meridian, making the total power in the right lens 90-degree meridian +3.00 D. The left lens minus cylinder component has no power in the 90-degree meridian. So the left lens also has a +3.00 D power in the 90-degree meridian. Since both lenses have the same power in the 90-degree meridian, there will be no vertical imbalance.
21. d. The difference between the two lens powers in the 90-degree meridian is 5.50 D. Vertical imbalance is

$$\Delta = cF = 1.0 \times 5.50 = 5.50$$

The most minus lens is the left lens. So the answer is 5.50Δ base up O.S. (Traditional slab-off prism is always base up.)

22. c. The power in the 90-degree meridian for the right lens is +4.00 D and for the left lens is +1.75 D. The difference in these powers is 2.25 D. The imbalance is

$$\Delta = cF = 0.8 \times 2.25 = 1.8$$

The least plus lens is the left lens, so 1.80Δ of slab off would be placed on the left lens.

23. a. The power in the 90-degree meridian for the right lens is

$$\begin{aligned} F_{90} &= F_{sph} + F_{cyl}\cos^2\theta \\ &= -5.50 + (-2.50)\cos^2 30 \\ &= -5.50 + (-2.50)(0.866)^2 \\ &= -5.50 + (-2.50)(0.75) \\ &= -5.50 - 1.875 \\ &= -7.375\,\text{D} \end{aligned}$$

The power in the 90-degree meridian for the left lens is

$$\begin{aligned} F_{90} &= F_{sph} + F_{cyl}\cos^2\theta \\ &= -2.50 + (-1.50)\cos^2 160 \\ &= -2.50 + (-1.50)(0.883) \\ &= -2.50 - 1.32 \\ &= -3.82\,\text{D} \end{aligned}$$

The difference in powers is 3.55 D.

The distance optical center will be at a height of 48/2 = 24 mm. The segment is at 20 mm so the drop is 4 mm. The reading level is 5 mm below that, so the reading level is 9 mm below the distance optical center. The vertical imbalance is

$$\Delta = cF = 0.9 \times 3.55 = 3.20$$

To the nearest 0.25 diopter, this is 3.25Δ.

24. b. The listed minimum fitting height is usually the distance from the fitting cross to the NRP. The distance used to calculate the vertical prismatic effect of one lens is the distance from the PRP to the NRP. That distance will be 14 mm minus 4 mm, or 10 mm. (This is converted to 1 cm to use with Prentice's rule.)
25. d. If the wearer does not drop the eyes fully into the near viewing area of a progressive addition lens, the slab line will be in their line of sight.
26. d. The difference in 90-degree meridian powers is 6.00 − 3.50 = 2.50 D.

$$\begin{aligned} \Delta &= cF \\ 1 &= c(2.50) \\ c &= \frac{1}{2.50} = 0.4\,\text{cm} = 4\,\text{mm} \end{aligned}$$

The slab will be 4 mm below the PRP and will be on the most minus or right lens. One needs to know the fitting cross height and the distance between the fitting cross and the PRP (usually 4 mm) before being able to give the slab height for the frame chosen.

27. b. False. Even though the full amount vertical imbalance correction is easiest to calculate, it is not necessarily what should always be used. The wearer may be comfortable with less than the full calculated amount. (See the section in this chapter entitled How the Prescriber Determines the Needed Amount of Imbalance Correction.)
28. a. True. Prentice's rule works correctly in the context of a single, hypothetically thin lens. However, prismatic effect at a given point on a lens is also influenced by lens thickness and base curve. So two lenses having different forms may not have the same prismatic effect.
29. a. True. By changing parameters, such as base curve and lens thickness, magnification changes. Because magnification changes, so does prismatic effect. Thus, any amount of correction for aniseikonia will lessen the need for as much vertical imbalance correction.
30. b.
31. d. The base direction of the prism used will always be placed in the direction that the eye is physically displaced. In other words, if the eye appears too high, use base-up prism. If the eye turns in, use base-in prism. If this is done, then to an observer, the wearer's eye will appear to be displaced toward the apex of the prism. Such prism is called *inverse prism* because it is opposite to what would normally be prescribed for a seeing eye.
32. c. We need to make the vertical dimension of the nonseeing eye look smaller. This would require minus power. But since the horizontal dimension matches the seeing eye, there should be no power in the horizontal meridian, which means using a minus cylinder lens whose axis is 180. The minus power of a plano minus cylinder is in the 90-degree vertical meridian. There is no power in the horizontal, 180-degree axis meridian.

Chapter 22

1. b. False. The shorter the wavelength the higher the energy and greater likelihood of damage.
2. b. False. Long-term lower level exposure to UV radiation can cause cumulative damage over time.
3. b. False. Working in low levels of illumination becomes increasingly difficult with age.
4. True. Once the AR coating is applied, the lens will not be able to be tinted.
5. a. True.
6. b. False. *Any* tint that cuts down on already dim illumination further reduces visual acuity, offsetting any reduction in headlight glare.
7. a. True.
8. a. True. The AR coating increases transmission, which helps with night time visual acuity.
9. a. True.
10. b. False. AR coating the back surface of a sunglass lens greatly reduces any mirror effect from objects behind the wearer and keeps the wearer from seeing their own eyelashes. These reflections otherwise interfere with vision through the sunglasses.
11. b. Ultrasonic cleaning is damaging to antireflection, color, and mirror coatings.
12. b. False. Plastic lenses may be dyed to absorb short wavelengths, which (1) helps reduce glare because older crystalline lenses will fluoresce with certain wavelengths and (2) will increase contrast.
13. b. False. Many colors of lenses will create more color confusion for people with color vision deficiency. Lenses that retain an even transmission of all colors do best.
14. e. One positive characteristic of vacuum color-coated lenses is their evenness of transmission across the entire surface of the lens.
15. a. UVA is closest to the visible spectrum and has the longest wavelength of the three types of UV radiation.
16. d. The answer will become clear by viewing the transmission curves in the UV and short-wavelength region for each of these lens types.
17. e
18. a
19. b. Because of the evenness of transmission across all colors, the gray tint does not create color confusion for individuals with color vision deficiency.

20. d. A green lens has its highest visible light transmission in the central portion of the visible spectrum.
21. a. Lenses should not be AR coated after having been worn as they will have microscratches. These scratches may not be perceived before being AR coated but will show up after the AR-coating process.
22. c. The lens is thinner along the axis of the plano minus cylinder. The lens becomes thicker farther from the 180-degree axis, becoming increasingly darker.
23. a. Yellow is in the middle of the visible spectrum. The single-layer AR coating is most effective for yellow but not as effective for other colors. The farther from the central yellow wavelength, the more the light is reflected. Blue and red are farthest away from yellow. They reflect the most. When combined, their reflections give a bluish-purple reflex color.
24. a. True. Light reflected from the inside of the windshield of a car is horizontally polarized and thus extinguished by polarized sunwear.
25. b
26. b. When light is reflected from a horizontal reflective surface like water, sand, or snow, the reflected light is horizontally polarized.
27. c

$$\begin{aligned} n_{\text{Film}} &= \sqrt{n_{\text{Lens}}} \\ &= \sqrt{1.66} \\ &= 1.288 \end{aligned}$$

28. b. Using ultimate transmission, multiply the two transmission factors: $0.50 \times 0.40 = 0.20$.

    This results in a transmission factor of 0.20, or 20%, transmission.
29. a. Use the ultimate transmission formula to find the answer.

$$\begin{aligned} T_{\text{U}} &= 0.55 \times 0.91 \times 0.28 \times 0.78 \\ &= 0.11 = 11\% \end{aligned}$$

30. b
    1. Find the reflection factor for the first surface.

$$\begin{aligned} I_{\text{R}} &= \left[\frac{n' - n}{n' + n}\right]^2 \times 1 \\ &= \left[\frac{1.73 - 1}{1.73 + 1}\right]^2 \times 1 \\ &= \left[\frac{0.73}{2.73}\right]^2 \\ &= 0.2674^2 \\ &= 0.072 \end{aligned}$$

    2. Find the transmission factor for the first surface.

$$1.000 - 0.072 = 0.928$$

    3. Find the transmission factor for the second surface.
       The transmission factor for the second surface is the same as the transmission factor for the first surface, or 0.928.
    4. Find the ultimate transmission for the lens.

$$\begin{aligned} T_{\text{U}} &= T_{Surface1} \times T_{lens} \times T_{Surface\,2} \\ &= 0.928 \times 1 \times 0.928 \\ &= 0.861 \textit{ or } 86.1\% \end{aligned}$$

31. d

$$\begin{aligned} \text{Opacity} &= \frac{1}{\text{Transmission}} \\ O &= \frac{1}{0.41} \\ &= 2.44 \end{aligned}$$

Chapter 23

1. a. True. Lens coatings are typically harder that the plastic substrate of the lens. When they crack, the extra energy released by the sudden crack may cause the lens to break when it otherwise may not have broken.
2. c. A colmascope is basically two polarizers with space in between and a light source behind. When the lens is placed between the two polarizers, any stress within the lens will show up. A colmascope is also called a *polariscope*.
3. d
4. b
5. b. Both polycarbonate and Trivex materials will pass ANSI Z87.1 safety standards for impact-rated lenses. Other materials listed as possible answers will not.
6. b. Plastic lenses may be batch tested. With some exceptions, glass lenses must be individually tested. Single-vision glass lenses are not one of those exceptions.
7. b. False. Although it might seem that rimless and semirimless frames should not be permitted as safety frames, rimless mountings and lenses must undergo the same rigorous testing as required for other safety frames and lenses. If they pass, they may be used.
8. b. False. If the prescriber feels that a certain lens material is warranted, it may be included in the prescription (e.g., polycarbonate or Trivex material for a monocular individual).
9. b. False. It is the responsibility of the dispenser to verify that protective eyewear is indeed protective.
10. d. Dress eyewear.
11. e. FDA requirements are performance based, not thickness based.
12. b. Waivers signed by the wearer to avoid clear regulations are not valid. Note that even though answer b is correct, the incidence of this situation occurring is extremely rare.
13. c
14. b. False. All sunglasses must be impact resistant to the same level as dress eyewear.
15. c. Back-surface scratches weaken lenses considerably more than front-surface scratches, even though front-surface scratches do weaken the lens somewhat.
16. c
17. a
18. a
19. c
20. b. False. Do not put lenses that are not safety lenses in a safety frame. These could be mistaken for safety glasses because of the frame markings and worn inappropriately.
21. b. False. Any time safety frames are used, only appropriately marked safety lenses are to be worn in the frame.
22. b. False. Only a heat-tempered glass lenses can be identified with a colmascope alone. A chemtempered lens must be immersed in a glycerin solution while viewing it between crossed polarizing filters. Then it will show a bright band around the edge of the lens if it has been chemically tempered.

23. e. Because the lens has its front surface in water (index 1.333) instead of air (index 1.0), the refractive power of the lens will be reduced unless the lens surface has zero power to start with.
24. d. Billiards. Presbyopic individuals may require a small increase in plus power in the distance prescription with a compensating change in add power to offset the changed distance power.
25. a. True. Both call for sports eyewear that complies with the ASTM F803 standard.
26. b. False. When even a large ball, such as a soccer ball, strikes the eye, the blunt trauma can produce a shock wave impact that causes the eyeball to distort then rebound with a large amount of force, resulting in severe damage.

Chapter 24

1. a. A single-vision lens corrects for one viewing distance.
2. c. A frame tracer transfers the shape and dimensions of a frame electronically to a lens edger.
3. d
4. c. The lensmeter dots indicate horizontal, not cylinder, axis or major lens meridians.
5. d. The major reference point indicates the point on the lens where the prism amount called for is located. If no prism is called for, the MRP and the optical center will be at the same location.
6. d. The NRP of a progressive addition lens is much lower in the lens.
7. c. When the lens has prescribed prism, the optical center will be at a displaced location.
8. d. A sphere lens without prescribed prism may be rotating around its optical center without affecting other optical components.
9. b. The PRP is where prism amounts are verified. The distance power must be measured at a higher location because the progressive power begins to change at the location of the PRP—which is where the progressive zone begins.
10. False. Patterns are measured in the same way lens shapes are measured, using the boxing system.

11. d

$$\begin{aligned}\text{Decentration per lens} &= (\text{A} + \text{DBL} - \text{PD})/2\\ &= (48 + 18 - 60)/2\\ &= 3\text{ mm}\end{aligned}$$

12. b

$$\begin{aligned}\text{DBC} &= \text{A} + \text{DBL}\\ &= 47 + 20\\ &= 67\text{ mm}\end{aligned}$$

13. b

$$\begin{aligned}\text{Decentration per lens} &= (\text{A} + \text{DBL} - \text{PD})/2\\ &= (52 + 16 - 70)/2\\ &= (-2)/2\\ &= -1\text{ or }1\text{ mm outward}\end{aligned}$$

14. d

$$\begin{aligned}\text{Decentration} &= (\text{A} + \text{DBL})/2 - \text{Monocular PD}\\ &= (52 + 18)/2 - 32\\ &= 35 - 32\\ &= 3\text{ mm inward}\end{aligned}$$

15. e

$$\begin{aligned}\text{Vertical decentration} &= \text{MRP height} - \text{B}/2\\ &= 23 - 40/2\\ &= 3\text{ mm up}\end{aligned}$$

16. c

$$\text{Edger setting} = 62 - 15 = 47$$

GLOSSARY

@ Symbol for at or in the same meridian as.

Δ Symbol for *prism* power. When following a number, it denotes the units known as prism diopters. (*See* Diopter, prism.)

∇ Symbol for *prism* power. When following a number, it denotes the units known as prism centrads. (*See* Centrad.)

⌒ Symbol for in combination with.

^ Symbol indicating that the lens power is compensated for as-worn or position of wear measurements. This carat mark is placed as a semivisible symbol on the front surface of a lens approximately 17 mm temporal to the optical center of a single-vision or multifocal lens. On a progressive addition lens, the expected location of the semivisible symbol would be to the temporal side of the semivisible marked add power.

180-degree line A synonym for horizontal midline.

A

A The horizontal dimension of the boxing system rectangle that encloses a lens or lens opening.

Abbé value *See* value, Abbé.

aberration The resulting degradation of an image that occurs when a point source of light does not result in a single-point image after going through the lens or lens system.

aberration, chromatic The type of aberration that causes light of different wavelengths (colors) to be refracted differently through the same optical system.

aberration, lateral chromatic An aberration that produces images of slightly different sizes at the focal length of the lens, depending upon the color of the light. (Synonym: *chromatic power.*)

aberration, longitudinal chromatic Occurs when a point light source that is composed of several wavelengths (such as white light) forms a series of point images along the optical axis. Each of these images is a different color, and each has a slightly different focal length.

aberration, monochromatic An aberration that is present even when light is made up of only one wavelength (one color).

aberration, spherical A monochromatic aberration that occurs when parallel light from an object enters a large area of a spherical lens surface and peripheral rays focus at different points on the optic axis than do paraxial rays.

absolute refractive index *See* index, absolute refractive.

accurate sag formula *See* formula, accurate sag.

achromatic lens *See* lens, achromatic.

actual power *See* power, actual.

add *See* addition, near.

add, nasal The modification of an existing spectacle lens shape for the purpose of creating a better frame fit by allowing more lens to remain in the inferior nasal position after edging the lens than would be otherwise indicated by the original shape.

addition, near The plus power a multifocal lens segment has that is added to the power already present in the main portion of the lens.

age-related maculopathy *See* maculopathy, age-related.

alignment, horizontal The alignment of the right and left horizontal midlines in a pair of spectacles with a single horizontal plane (neither lens is higher than the other when viewed from the front).

alignment reference marking (ARM) *See* marking, alignment reference.

alignment, standard An impersonal standard, independent of facial shape, for the alignment of spectacle frames.

alignment, vertical Lack of deviation of the two spectacle lenses from the vertical plane (one being neither farther forward nor backward than the other).

allowance, grinding Synonym for wheel differential.

allowance, vertex power The amount by which the front surface curvature of a lens must be flattened to compensate for a thickness-related gain in power.

Alvarez lens *See* lens, Alvarez.

American endpiece *See* endpiece, American.

American National Standards Institute An industry-based, nongovernmental standards-setting association. The American National Standards Institute (ANSI) is an agency that addresses standards throughout all of industry within the United States, of which the ophthalmic industry is only a small part. ANSI sets standards for aspects of the ophthalmic industry that includes lenses, frames, and contact lenses.

ametropia The refractive condition that occurs when parallel rays entering the eye do not focus on the retina when the eye is not accommodating.

ametropia, axial Ametropia that occurs because the eye is too long or too short.

ametropia, refractive Ametropia that occurs because the refractive elements (surfaces) of the eye are too strong or too weak.

analyzer, lens A trade name for an automated lensmeter.

angle of deviation The difference between the angle of incidence and the angle of refraction.

angle, apical The angle formed by the junction of two nonparallel prism surfaces.

angle, Brewster's The angle of incidence at which reflected light from a refracting surface is completely polarized.

angle, crest The angle from the tip to the top of the nose (between the eyes) compared with a vertical plane roughly parallel to the brows and cheeks.

angle, effective diameter The angle from the 0-degree side of the 180-degree line to the axis of the effective diameter. The angle is referred to by the letter *X* and is measured using the right lens.

angle, frontal 1. The angle with which each side of the nose deviates from the vertical. 2. The angular amount the nose pad face deviates from the vertical when the frame is viewed from the front.

angle, pantoscopic 1. In standard alignment: that angle by which the frame front deviates from the vertical (lower rims farther inward than upper rims) when the spectacles are held with the temples horizontal. 2. In fitting: that angle that the frame front makes with the frontal plane of the wearer's face when the lower rims are closer to the face than the upper rims (opposite-retroscopic angle). (Synonym: *pantoscopic tilt.*)

angle, retroscopic That angle that the frame front makes with the frontal plane of the wearer's face when the lower rims are farther from the face than the upper rims (opposite-pantoscopic angle). (Synonym: *retroscopic tilt.*)

angle, splay 1. That angle formed by the side of the nose with a straight anterior-posterior surface that would bisect it vertically (also called *transverse angle*). 2. The angle the face of a nose pad makes with a plane perpendicular to that of the frame front when viewed from above.

angle, temple fold The angle formed when a temple is folded to a closed position when compared to the horizontal and viewed from the back.

angle, vertical When viewed from the side, that angle formed between the plane of the lenses and the long axis of the adjustable nose pads.

angle, wrap The angle that each side of a frame front is angled from an otherwise unbent, straight-across position.

aniseikonia A relative difference in the size (and/or the shape) of the images seen by the right and the left eyes.

aniseikonia, anatomical When aniseikonia is caused by the anatomical structure, such as an unequal distribution of the retinal elements (rods and cones) of one eye compared with the other.

aniseikonia, asymmetrical A form of aniseikonia in which there is a progressive increase or decrease in image size across the visual field of one eye compared with the other.

aniseikonia, induced Aniseikonia that occurs when a size difference in right and left eye images is caused by an outside source, as from correcting ophthalmic lenses.

aniseikonia, inherent optical Aniseikonia that occurs when a size difference in right and left images is caused by the optics of the eye.

aniseikonia, meridional When one eye sees an image that is greater in size in one meridian than the corresponding image size for that same meridian in the other eye.

aniseikonia, physiological The slight difference in image sizes that occurs when, even though both eyes have the same amount of

refractive error (or none at all), the image in one eye will be slightly larger or smaller than the other. This occurs when the object is closer to one eye than it is to the other. Physiological aniseikonia helps in depth perception and determining the distance of the object from the observer.

aniseikonia, symmetrical Aniseikonia in which one eye sees an image that is symmetrically larger than that of the other eye. One image is equally larger in every meridian compared with the image of the other eye.

anisometropia A condition in which one eye differs significantly in refractive power from the other.

ANSI Abbreviation for American National Standards Institute.

antireflection coating *See* coating, antireflection.

antiscratch coating *See* coating, antiscratch.

aperture 1. An opening or hole that admits only a portion of light from a given source or sources. 2. The central, optically correct portion of a lenticular lens.

aperture, lens The portion of the spectacle frame that accepts the lens. (Synonym: *lens opening.*)

apex The junction point at which the two nonparallel surfaces of a prism meet.

aphake A person whose crystalline lens has been removed and not replaced with an intraocular lens implant.

apical angle *See* angle, apical.

apical scotoma *See* scotoma, apical.

approximate power Synonym for nominal power. *See* power, nominal.

AR An abbreviation for antireflection coating.

ARM Alignment reference marking. *See* marking, alignment reference.

arm Also called *bar, browbar*; in a semirimless mounting, the metal reinforcement that follows the upper posterior surface of a spectacle lens and joins the centerpiece to the endpiece.

arms, guard A synonym for pad arms.

arms, pad Metal pieces that connect adjustable nose pads to the front of a frame. (Synonym: *guard arms.*)

assistive power lens *See* lens, assistive power.

as-worn power *See* power, as worn.

aspheric surface *See* surface, aspheric.

aspheric lens *See* lens, aspheric.

aspheric lenticular *See* lenticular, aspheric.

aspheric, full-field *See* lens, full-field aspheric.

assistive power lens *See* lens, assistive power.

astigmatic difference *See* difference, astigmatic.

astigmatism The presence of two different curves on a single refracting surface on or within the eye. This causes light to focus as two line images instead of as a single point.

astigmatism, marginal *See* astigmatism, oblique.

astigmatism, oblique 1. An astigmatic eye condition whereby the major meridians of the correcting lens are at an oblique angle, between 30 and 60 degrees or 120 and 150 degrees. 2. The lens aberration that occurs when rays from an off-axis point pass through a spherical lens and light focuses as two line images instead of a single point. (Synonyms: *radial astigmatism, marginal astigmatism.*)

astigmatism, radial *See* astigmatism, oblique.

ASTM American Society for Testing and Materials.

atoric surface *See* surface, atoric.

autolensmeter A lensmeter that measures the power and prismatic effect of the lens in an automated fashion.

axial ametropia *See* ametropia, axial.

axis meridian *See* meridian, axis.

axis of a cylinder An imaginary reference line used to specify cylinder or spherocylinder lens orientation and corresponding to the meridian perpendicular to that of maximum cylinder power.

axis, optical That line which passes through the center of a lens on which the radii of curvature of the front and back surfaces fall.

axis, prism The base direction of an ophthalmic prism expressed in degrees.

B

B The vertical dimension of the boxing system rectangle that encloses a lens or lens opening.

back base curve *See* curve, back base.

back vertex power *See* power, back vertex.

bakelite One of the first plastics used to make frames. Bakelite is a synthetic resin invented around 1909 and was used for such items as pool balls, jewelry, buttons, radio cases, and lamps.

Balgrip mounting *See* mounting, Balgrip.

bar *See* arm.

barrel The housing for a screw on a pair of glasses.

barrel distortion *See* distortion, barrel.

base In a prism, the edge of maximum surface separation opposite the apex.

base curve *See* curve, base.

base down Vertical placement of prism such that the base is at 270 degrees on a degree scale.

base in Horizontal placement of prism such that the base is toward the nose.

base out Horizontal placement of prism such that the base is toward the side of the head.

base up Vertical placement of prism such that the base is at 90 degrees on a degree scale.

batch testing The practice of selectively testing a statistically significant number of lenses in a manufactured group.

BCD Boxing center distance. *See* distance, boxing center.

bent-down portion *See* earpiece.

best form lens *See* lens, corrected curve.

bevel The angled edge of the spectacle lens.

bevel, hidden An edged lens configuration that attempts to reduce the appearance of thickness by creating a small bevel with the rest of the lens edge remaining flat.

bevel, mini A lens edge configuration that has a bevel and an angled ledge.

bevel, pin Synonym for safety bevel.

bevel, safety 1. To remove the sharp interface between lens surface and bevel surface and the sharp point at the bevel apex. 2. The smoothed interface between lens surface and bevel surface and the smoothed lens bevel apex.

bevel, V A lens edge configuration having the form of a V across the whole breadth of the lens edge.

bicentric grinding *See* grinding, bicentric.

biconcave A term used to describe a lens that is inwardly curved on both surfaces.

biconvex A term used to describe a lens that is outwardly curved on both surfaces.

bifocal A lens having two areas for viewing, each with its own focal power. Usually the upper portion of the lens is for distance vision, and the lower portion is for near vision.

bifocal, blended A bifocal lens constructed from one piece of lens material and having the bifocal segment demarcation line smoothed out so as not to be visible to an observer.

bifocal, curved-top A bifocal lens having a segment that is round in the lower portion and gently curved on the top of the segment.

bifocal, Executive American Optical's trade name for the Franklin-style bifocal.

bifocal, flat-top A bifocal with a segment that is round in the lower half but flat on the top.

bifocal, Franklin A bifocal having a segment that extends the entire width of the lens blank.

bifocal, minus add A bifocal with a large, round segment at the top of the lens. The segment is powered for distance viewing and the rest of the lens for near viewing. (Synonyms: *upcurve bifocal, Rede-Rite bifocal.*)

bifocal, Panoptik A bifocal lens resembling a flat-top bifocal, but having a segment that has a slightly curved upper edge with rounded corners.

bifocal, Rede-Rite *See* bifocal, minus add.

bifocal, ribbon A bifocal with a segment that resembles a circle with the top and bottom removed.

bifocal, round seg A bifocal with a segment that is perfectly round. The width of the segment is normally 22, 25, or 38 mm.

bifocal, upcurve *See* bifocal, minus add.

binocular PD *See* PD, binocular.

bitoric lens *See* lens, bitoric.

blank geometrical center *See* center, blank geometrical.

blank seg drop *See* drop, blank seg.

blank seg inset *See* inset, blank seg.

blank, finished lens A lens that has front and back surfaces smoothed and polished to the desired powers but not yet edged to the shape of the frame.

blank, pattern A predrilled flat piece of plastic from which an edger pattern for a frame shape may be cut.

blank, rough A thick, round "lens" with neither side having the finished curvature. Both sides must yet be surfaced to bring the lens to its desired power and thickness.

blank, semifinished lens A lens with only one side having the desired curvature. The second side must yet be surfaced to bring the lens to its desired power and thickness.

bleaching, optical The lightening of a photochromic lens from exposure to red light or infrared radiation.

bleaching, thermal The lightening of a photochromic lens from exposure to heat.

blended bifocals *See* lens, blended bifocal.

blended myodisc *See* lens, blended myodisc.

block That which is attached to the surface of a lens to hold it in place during the surfacing or edging process.

blocker The device used to place a block on the lens to hold the lens in place during the surfacing or edging process.

blocker, layout A centering device with the capability of also blocking the lens. The layout blocker does not mark the lens first but blocks it immediately after centration.

blocking, finish The application of a holding block to an ophthalmic lens so that it may be edged to fit a frame.

blocking, surface The application of a holding block to an ophthalmic lens so that one side may be ground to the correct curvature and polished.

Boley gauge *See* gauge, Boley.

boost, power The low plus power added to the reading or near zone of an assistive power lens.

box, light A box with a white, translucent piece of plastic on top and a full spectrum bulb inside. When used in the optical laboratory, the white illuminated background serves as a backdrop for comparison of two lens colors.

boxing center *See* center, boxing.

boxing center distance *See* distance, boxing center.

boxing system *See* system, boxing.

Box-o-Graph A flat device containing grids and slides used in the measurement of pattern and edged lens size.

Brewster's angle *See* angle, Brewster's.

bridge The area of the frame front between the lenses.

bridge, comfort A clear plastic saddle-type bridge that is used on a metal frame.

bridge, keyhole The top, inside area of a keyhole bridge is shaped like an old-fashioned keyhole. From the top, it flares out slightly, resting on the sides of the nose, but not on the crest of the nose.

bridge, metal saddle A metal bridge for a spectacle frame that arches across in a thin band, sitting directly on the crest of the nose. (Synonym: *W bridge.*)

bridge, pad The bridge configuration commonly used in metal frames having adjustable nose pads.

bridge, saddle A frame bridge that is shaped like a saddle in a smooth curve and follows the bridge and sides of the nose smoothly.

bridge, semisaddle A bridge that looks much the same as a saddle from the front but has permanent, nonadjustable nose pads as part of the back of the bridge. (Synonym: *modified saddle bridge.*)

bridge, skewed That misalignment that occurs when one lens in a pair of spectacles is higher than the other, yet neither lens is rotated.

bridge-narrowing pliers *See* pliers, bridge-narrowing.

bridge-widening pliers *See* pliers, bridge-widening.

browbar *See* arm.

buildup pads *See* pads, buildup.

bushing A small, hollow cylindrical sleeve that fits into the hole in the lens through which a screw passes. Its purpose is to prevent stress and abrasion.

C

C The horizontal width of a lens or lens opening as measured at the level of its geometrical center. (Synonym: *datum length.*)

C size The circumference of an edged lens.

cable temple *See* temple, cable.

caliper, vernier A hand-held width-measuring device with a short graduated scale that slides along a longer graduated scale, allowing a measure of fractional parts or decimals. May be used to measure lens thickness.

carbon fiber A material made from strands of carbon fibers combined with nylon. When used for spectacle frames, it is thin and strong, but not adjustable.

carrier The outer, nonoptical portion of a lenticular lens.

cataract A loss in clarity of the crystalline lens of the eye which results in reduced vision or loss of vision.

cellulose acetate A material extracted from cotton or wood pulp and used extensively for making spectacle frames.

cellulose acetopropionate *See* propionate.

cellulose nitrate *See* zylonite.

cement lens *See* lens, cement.

center, blank geometrical The physical center of a semifinished lens blank or an uncut finished lens blank. The blank geometrical center is the center of the smallest square or rectangle that completely encloses the lens blank.

center, boxing The midpoint of the rectangle that encloses a lens in the boxing system.

center, cutting Synonym for mechanical center.

center, datum The midpoint of the datum length (C dimension) of a lens as measured along the datum or horizontal midline.

center, edging Synonym for mechanical center.

center, geometrical 1. The boxing center. 2. The middle point on an uncut lens blank.

center, mechanical The rotational center of a pattern found at the midpoint of the central pattern hole. (Synonyms: *cutting center, edging center.*)

center, optical That point on an ophthalmic prescription lens through which no prismatic effect is manifested. Abbreviated as OC.

center, reading That point on a lens at the reading level that corresponds to the near PD.

center, rotational The point on a pattern around which it rotates during edging.

center, seg optical That location on the segment of a bifocal lens that shows zero prismatic effect when no refractive power is in the distance portion of the lens.

centerpiece The portion of a rimless mounting consisting of bridge, pad arms, pads, and strap area.

Centrad ∇ A unit of measurement of the displacement of light by a prism. One centrad is the prism power required to displace a ray of light 1 cm from the position it would otherwise strike on the arc of a circle having a 1-m radius.

centration The act of positioning a lens for edging such that the lens will conform optically to prescription specifications.

chamfering The word *chamfer* means to bevel. In lens finishing, chamfering is taken to mean the act of smoothing off or safety beveling the sharp edges of a hole, slot, or notch drilled in a spectacle lens to prevent the chipping of the hole, slot, or notch when the spectacles are worn. ***NOTE:*** *Chamfering* and *safety beveling* are synonymous.

chassis The portion of the frame that includes the eyewire and center or bridge section. Commonly refers to the metal eyewire and bridge of a combination frame.

chemical tempering *See* tempering, chemical.

chemtempering *See* tempering, chemical.

chipping pliers *See* pliers, chipping.

chord A straight line that intersects two points of an arc.

chord diameter *See* diameter, chord.

chromatic aberration *See* aberration, chromatic.

chromatic power *See* aberration, lateral chromatic.

circumference gauge *See* gauge, circumference.

clock, lens A small, pocket-watch–sized instrument for measuring the surface curve of a lens. Also called a *lens measure* or *lens gauge.*

clock, seg Designed like a conventional lens clock (lens measure) except that the three points of contact are closely spaced. Now most lens clocks also have narrowly spaced contact points so that there is little if any difference between a newer lens clock and a seg clock.

coating, antireflection A thin layer or series of layers of material applied to the surface of a lens for the purpose of reducing unwanted reflections from the lens surface and thus increasing the amount of light that passes through to the eye.

coating, antiscratch A thin, hard coating applied to plastic lens surfaces to make them more resistant to scratching.

coating, color A coating applied to the surface of a lens for the purpose of reducing light transmission.

coating, dielectric A mirrorlike coating that reflects certain wavelengths selectively.

coating, edge Application of color to the edge of a lens for the purpose of decreasing edge visibility.

coating, flash A metalized lens coating that absorbs light and has only a hint of reflectance. Also called *flash mirror coating.*

coating, metalized A thin layer of metal on the front of the lens to both absorb and reflect light.

coating, mirror A coating applied to a lens causing it to have the same properties as a two-way mirror.

coating, scratch-resistant A synonym for antiscratch coating.

cold snap *See* snap, cold.

collar *See* shoe.

colmascope An instrument that uses polarized light to show strain patterns in glass or plastic lenses. (Synonym: *polariscope.*)

color coating *See* coating, color.

color, reflex The residual color of an antireflection-coated lens.

coma The lens aberration that occurs when the object point is off the axis of the lens. Instead of forming a single, point image off the optic axis, the image appears shaped like a comet or pointed ice cream cone.

combination frame *See* frame, combination.

comfort bridge *See* bridge, comfort.

comfort cable temple *See* temple, cable.

compensated power *See* power, compensated.

compensated segs *See* segs, R-compensated.

compounding (of prism) The process of combining two or more prisms to obtain the equivalent prismatic effect expressed as a single prism.

concave An inward-curved surface.

conditioner, lens A specially formulated solution into which a plastic lens is immersed before being tinted. The purpose of lens conditioner is to prepare the lens for a fast and even uptake of dye.

conjugate foci *See* foci, conjugate.

contour plot *See* plot, contour.

convergence 1. An inward turning of the eyes, as when looking at a near object. 2. The action of light rays traveling toward a specific image point.

convertible temple *See* temple, convertible.

convex An outward-curved surface.

coolant A liquid used to cool and lubricate the lens/grinding-wheel interface during the grinding process.

coquille The thin nonpowered demonstration lens that comes in a spectacle frame to hold the shape of the frame as intended and to more realistically simulate the appearance of the frame for the prospective wearer. (Synonyms: *dummy lens, demo lens.*)

corrected curve lens *See* lens, corrected curve.

corridor, progressive The area of a progressive-addition lens between the distance and near portions where the power of the lens is gradually changing.

cosine For a right triangle, the ratio of the side adjacent to the angle considered to the hypotenuse. $\text{Cosine} = \frac{\text{Adjacent}}{\text{Hypotenuse}}$.

cosine-squared formula *See* formula, cosine-squared.

countersink curve *See* curve, countersink.

cover lens *See* lens, cover.

CR-39 A registered trademark of Pittsburgh Plate Glass Co. for an optical plastic known as Columbia Resin 39. It has been the standard material from which conventional plastic lenses are made.

crazed The cracked, dried-mud appearance of a lens with a damaged or defective coating.

crest The highest and centermost part of the bridge of a spectacle frame.

crest angle *See* angle, crest.

cross curve *See* curve, cross.

cross, fitting A reference point normally found 4 mm above the prism reference point (PRP) on progressive addition lenses. The fitting cross is positioned in front of the pupil.

cross, power A schematic representation on which the two major power meridians of a lens or lens surface are depicted.

crown glass *See* glass, crown.

curl *See* earpiece.

curvature The reciprocal of the radius of curvature of a curved surface quantified in reciprocal meters (m^{-1}) and abbreviated by *R*.

curvature of field The lens aberration that causes the spherical power of the lens to be off-power in the periphery when compared with the center of the lens. For a flat object, this results in a curved image. (Synonym: *power error.*)

curve, back base The weaker back-surface curve of a minus cylinder-form lens. When the lens is a minus cylinder-form lens, the back base curve and the toric base curve are the same.

curve, base The surface curve of a lens that becomes the basis from which the other remaining curves are calculated. This is usually the front surface spherical curve of the lens.

curve, countersink For the manufacture of fused-glass semifinished bifocal and trifocal lenses, the countersink curve is that curve that is ground into the main lens in the area where the segment is to be placed. The countersink curve matches the back curve of the bifocal or trifocal segment. When the segment is placed on the countersink curve of the main lens, the two may then be fused together.

curve, cross The stronger curve of a toric lens surface.

curve, nominal base A 1.53 index–referenced number assigned to the base curve of a semifinished lens. For moderately powered crown-glass lenses, the needed back surface tool curve may be found by subtracting the nominal base curve from the prescribed back vertex power.

curve, tool The 1.53 index–referenced surface power of a lap tool used in the fining and polishing of ophthalmic lenses.

curve, true base Synonym for true power.

cut, nasal The removal of an inferior, nasal portion of the lens shape to create a better frame fit.

cutting line *See* line, cutting.

cylinder A lens having a refractive power in one meridian only and used in the correction of astigmatism.

cylinder power *See* power, cylinder.

D

D An abbreviation for diopter of refractive power. *See* diopter, lens.

datum center *See* center, datum.

datum center distance *See* distance, datum center.

datum line *See* line, datum.

datum system *See* system, datum.

DBC Distance between centers.

DBL Distance between lenses.

DCD Datum center distance.

decentration 1. The displacement of the lens optical center or major reference point away from the boxing center of the frame's lens aperture. 2. The displacement of a lens optical center away from the wearer's line of sight for the purpose of creating a prismatic effect.

decentration, effective The shortest distance from the axis of a decentered cylinder to the point from which decentration began.

degression The decrease in plus power measured from the lower viewing area to the upper viewing area of an occupational progressive addition lens.

degressive power lens *See* lens, degressive power.

demand, dioptric The inverse of the reading distance in meters that is, independent of actual bifocal addition power.

demo lens *See* coquille.

depth, middatum The depth of an edged lens measured through the datum center.

depth, reading The vertical position in the lens through which the wearer's line of sight passes when reading.

depth, sagittal (sag) The height or depth of a given segment of a circle.

depth, seg The longest vertical dimension of the lens multifocal segment before the lens has been edged.

deviation, angle of *See* angle of deviation.

diameter, chord The length of the chord of an arc or circle. When processing spectacle lenses, this diameter is equal to the minimum blank size required for cutting a lens but does not include the 2-mm safety factor for lens chipping that is included in the minimum blank size formula.

diameter, effective Twice the longest radius of a frame's lens aperture as measured from the boxing center. Abbreviated ED.

dielectric coating *See* coating, dielectric.

difference, astigmatic The linear distance between the two line foci that occurs in the lens aberration called *oblique astigmatism.* When expressed in diopters, this difference is called the *oblique astigmatic error.*

difference, frame In the boxing system, the difference between frame A and frame B dimensions expressed in millimeters. (Synonym: *lens difference.*)

difference, pattern In the boxing system, the difference between pattern *A* and *B* dimensions expressed in millimeters.

differential, wheel The difference in millimeters between the size of the lens produced in roughing and finishing operations during edging.

diopter, lens (D) Unit of lens refractive power equal to the reciprocal of the lens focal length in meters.

diopter, prism (Δ) The unit of measurement that quantifies prism-deviating power; one prism diopter (1Δ) is the power required to deviate a ray of light 1 cm from the position it would otherwise strike on a plane 1 m away from the prism.

dioptric demand *See* demand, dioptric.

disability glare *See* glare, disability.

discomfort glare *See* glare, discomfort.

dispersion, mean The quantity $(n_F - n_C)$, which is the index of refraction for blue light minus the index of refraction for red light. This quantity helps to define the chromatic nature of a lens material.

dispersive power *See* power, dispersive.

dissimilar segs *See* segs, dissimilar.

distance between centers (DBC) In a frame or finished pair of glasses, the distance between the boxing (geometrical) centers. (Synonym: *geometrical center distance.*)

distance between lenses (DBL) In the boxing system, the distance between the two boxed lenses as positioned in the frame. It is the shortest distance between a lens pair measured from the inside nasal eyewire grooves across the bridge area at the narrowest point (usually synonymous with *bridge size*).

distance reference point *See* point, distance reference.

distance, boxing center Synonym for distance between centers.

distance, datum center The distance between the datum centers in a frame or pair of glasses as used in the older datum system of measuring frames and lenses.

distance, frame center Is a synonym for distance between centers and geometrical center distance. *See* distance, geometrical center.

distance, geometrical center The distance between the boxing (geometrical) centers of a frame.

distance, interpupillary (PD) The distance from the center of one pupil to the center of the other when either an infinitely distant object is being viewed (distance PD) or a near object is being viewed (near PD).

distance, near centration The distance between the geometrical centers of the near segments.

distance, vertex The distance from the back surface of the lens to the front of the eye.

distometer An instrument used to measure vertex distance.

distortion The lens aberration that results when image magnification changes from the center to the edge of the image, resulting in either a barrel-like minification or pincushion-like magnification when compared with the object.

distortion, barrel The type of distortion normally caused by a minus lens that results in the image of a square object taking on a smaller barrel-shaped appearance.

distortion, pattern The loss of correct edged lens shape resulting from use of a pattern that is too large or too small in comparison with the lens size being edged.

distortion, pincushion The type of distortion normally caused by a plus lens that results in the image of a square object taking on a larger pincushion-shaped appearance.

divergence The action of light rays going out from a point source.

double gradient tint *See* tint, double gradient.

double-D lens *See* lens, double-D.

double-segment lens *See* lens, double-segment.

doublet *See* lens, achromatic.

dress eyewear *See* eyewear, dress.

dress To reshape the cutting surface of a grinding wheel.

drop-ball test *See* test, drop-ball.

drop, blank seg The vertical distance from the blank geometrical center to the top of the multifocal segment.

drop, seg 1. The vertical distance from the major reference point (MRP) to the top of the segment when the segment top is lower than the MRP. 2. The vertical distance from the horizontal midline to the top of the segment when the segment top is lower than the horizontal midline (laboratory usage). (Antonym: *seg raise*.)

DRP An abbreviation for distance reference point. *See* point, distance reference.

dummy lens *See* coquille.

E

ear That portion of the strap area on a classic or antique-type rimless mounting that extends from the shoe, contacting the surface of the lens. (Synonym: *tongue*.)

earpiece That part of the temple that lies past the temple bend. (Synonym: *curl*.)

ED The abbreviation for effective diameter. *See* diameter, effective.

edge coating *See* coating, edge.

edge, rolled A lens edge configuration that reduces minus lens edge thickness by rounding out the back surface edge of the lens.

edger The piece of machinery used to physically grind the uncut lens blank to fit the shape of the frame.

edger, hand A grinding wheel made especially for changing a lens shape or smoothing a lens edge by hand. Synonym; hand stone.

edger, patterned A lens edger that uses physical patterns to produce the correct lens shape.

edger, patternless An edger that uses an electronic tracing of a lens shape rather than a physical pattern to produce the correct lens shape.

effective decentration *See* decentration, effective.

effective diameter *See* diameter, effective.

effective diameter angle *See* angle, effective diameter.

effective power *See* power, effective.

eikonometer, space An instrument used to quantitatively measure image size differences between right and left eyes.

ellipse, Tscherning's The elliptical-shaped graph that shows the best lens form(s) a lens can have for eliminating oblique astigmatism.

emmetrope A person without refractive error.

emmetropia The absence of refractive error.

endpiece angling pliers *See* pliers, endpiece angling.

endpiece One of the two outer areas of the frame front to the extreme left and right where the temples attach.

endpiece, American An older classification of a spectacle frame's metal endpiece that has a stop protruding from the single barrel on the temple preventing the temple from opening out too far.

endpiece, butt-type A spectacle frame endpiece construction in which the front is straight, the temple butt is flat, and both meet at a 90-degree angle.

endpiece, English An older classification of a spectacle frame's metal endpiece that has a stop, or knuckle, that comes out around the hinge barrels and prevents the temples from opening out too widely.

endpiece, French An older classification of metal endpiece in which the temple is slotted between the two barrels and the stop is on the frame front as an extension of the single barrel.

endpiece, mitre-type A spectacle frame endpiece construction in which the frame front contact area and temple butt meet at a 45-degree angle.

endpiece, turn-back A spectacle frame endpiece design in which the frame front bends around and meets the temple end to end.

English endpiece *See* endpiece, English.

equation, Fresnel The formula for determining the amount of light that will be reflected from an uncoated lens surface that is based on the index of refraction of the lens material.

Equithin A term used by the Varilux Corporation when referring to the use of yoked prism for thickness reduction on a pair of progressive addition lenses. *See* also prism, yoked.

equivalent, spherical The sum of the spherical component and one half of the cylinder component of an ophthalmic lens prescription.

equiconcave lens *See* lens, equiconcave.

equiconvex lens *See* lens, equiconvex.

error, image shell A quantitative measure of the lens aberration called *curvature of field* or *power error*. The image shell error is the dioptric difference between the place where the peripheral image actually focuses and where it should focus.

error, oblique astigmatic The "astigmatic difference" that occurs in the aberration of oblique astigmatism as expressed in diopters.

error, power *See* curvature of field.

Executive bifocal *See* bifocal, Executive.

extractor, screw A device that resembles a screwdriver but has a barbed tip instead of a blade. The barbed tip digs into a damaged screw head or the remaining tip of a broken-off screw and is turned to remove the damaged or broken screw.

eyesize In the boxing system, the A dimension. (The horizontal dimension of the lens opening of a frame, which is bounded by two vertical lines tangent to the left and right sides of that lens opening.)

eyewear, dress Eyewear designed for everyday use.

eyewear, safety Eyewear designed to be worn in situations that could be potentially hazardous to the eyes and thus must meet higher standards of impact resistance than conventional eyewear.

eyewear, sports Eyewear designed to protect the eyes and/or enhance vision in specific sports situations. What is appropriate will vary dramatically depending upon the sport.

eyewire The rim of the frame that goes around the lenses.

eyewire forming plier *See* plier, eyewire forming.

eyewire shaping plier Eyewire forming plier.

F

F Often used in equations to denote lens refractive power in diopters. Alternative symbol for *F* is *D*.

face form *See* form, face.

facet An edge configuration resembling the appearance of beveled glass that is sometimes used with high-minus lenses to reduce edge thickness and weight.

factor, power That part of spectacle magnification that is determined by the power and position of the lens.

factor, shape That part of spectacle magnification that is determined by the shape of the lens, including front curve, refractive index, and lens thickness.

factor, transmission The ratio of light emerging from a lens compared to light entering the lens. If all light is transmitted, the transmission factor of the lens is 1.0. If only half the light emerges from the lens, the transmission factor is 0.5. A lens with a transmission factor of 0.5 has a percent transmission of 50%.

farsightedness *See* hyperopia.

FDA U.S. Food and Drug Administration.

figure-8 liner *See* liner, figure 8.

file, pillar A general purpose file used in dispensing.

file, rat-tail A file that is used in dispensing on drilled lenses to (1) reduce lens thickness in an area to allow for proper lens strap grasp or (2) to smooth the edges of the drilled lens hole.

file, ribbon *See* file, slotting.

file, riffler Spoon-shaped file used in dispensing that is good for getting at small, hard-to-reach areas. It is especially well-suited for filing the end of a lens-mounting screw without damaging the surface of the lens.

file, slotting Used for reslotting screws or making a slot where none previously existed.

file, zyl Used in dispensing to file plastic parts of a frame.

filter, notch An absorptive characteristic that selectively filters light by cutting one or more notches in the visible spectrum. The "notch" is typically a narrow, sharply-bordered portion of the visible spectrum where all or most of the light in that area is filtered out compared to the surrounding spectral areas.

finger-piece pliers *See* pliers, finger-piece.

fining When surfacing a lens, *fining* is the process of bringing a roughly generated lens surface to the smoothness needed so that it may be polished.

finished lens *See* lens, finished.

finishing The process in the production of spectacles that begins with a pair of uncut lenses of the correct refractive power and ends with a completed pair of spectacles.

first focal length *See* length, first focal.

first principal focus *See* focus, first principal.

fitting cross *See* cross, fitting.

flash Synonym for swarf.

flash coating *See* coating, flash.

flat surface touch test *See* test, flat surface touch.

flat top bifocal *See* bifocal, flat-top.

focal point *See* point, focal.

focal power *See* power, focal.

foci, conjugate Object and image points for a lens or lens system that correspond. In simplified terms, light rays originating at one point will be focused at the other.

focimeter Synonym for lensmeter.

focus, first principal The focal point from which parallel light rays leaving the back surface of a lens originated. For positive lenses this is a real focal point; for negative lenses, a virtual focal point. (Synonym: *primary focal point.*)

focus, second principal That point at which parallel light rays entering the front surface of a lens are brought to focus. For positive lenses the focal point is real; for negative lenses, a virtual focal point. (Synonym: *secondary focal point.*)

fork, centering A forklike device that was used to hold a lens in position at a specific orientation for blocking or for placing a lens in an older-style edger without being blocked.

form, face An expression of the extent to which the curve in the frame front varies from the classical four-point touch position, taking on the curved form of the face.

form, minus cylinder The form a spectacle lens prescription takes when the value of the cylinder is expressed as a negative number.

form, plus cylinder The form a spectacle lens prescription takes when the value of the cylinder is expressed as a positive number.

former British equivalent of *pattern.*

formula, accurate sag The formula used to find sagittal depth, which states that $s = r - \sqrt{(r^2 - y^2)}$, where s is the sagittal depth, r is the radius of curvature of the surface, and y is the semidiameter of the chord.

formula, cosine-squared A formula used to obtain the "power" of an oblique cylinder, usually in the 90-degree meridian.

formula, lensmaker's A formula used to find the dioptric power of a surface or radius of curvature. The formula states that $F = (n' - n)/r$ where F is the lens refractive power in diopters, n' is the refractive index of the lens, and n is the refractive index of the media surrounding the lens.

formula, sine-squared A formula used to obtain the "power" of cylinder in an oblique meridian. When the cylinder axis is tilted, the unknown power is usually in the 180-degree meridian.

four-point touch *See* touch, four-point.

frame center distance *See* distance, frame center.

frame center distance *See* distance, geometrical center.

frame difference *See* difference, frame.

frame PD Synonym for distance between centers or geometrical center distance.

frame tracer *See* tracer, frame.

frame, combination 1. A frame having a metal chassis with plastic top rims and temples. 2. A frame having some major parts of plastic construction and some of metal.

frame, nylon cord A frame that holds the lenses in place by means of a nylon cord that fits into a groove around the edge of the lens. Sometimes called a *string mount frame* or a *rimlon* frame. Though not accurate, nylon cord frames are often referred to as *semirimless frames.*

frame, shell An older expression referring to a plastic frame. Derived from when tortoise shell was used as a frame material.

frame, string mounted *See* frame, nylon cord.

Franklin bifocal *See* bifocal, Franklin.

French endpiece *See* endpiece, French.

Fresnel equation *See* equation, Fresnel.

Fresnel lens *See* lens, Fresnel.

Fresnel prism *See* prism, Fresnel.

front That portion of the spectacles that contains the lenses.

front vertex power *See* power, front vertex.

front, wave The outer border formed by light rays diverging from their point of origin.

frontal angle *See* angle, frontal.

front-to-bend (FTB) Temple length expressed as the distance from the plane of the frame front to the bend of the temple.

FTB *See* front-to-bend.

full-field aspheric *See* aspheric, full-field.

fused multifocals *See* multifocals, fused.

G

gauge, Boley A measuring gauge that may be used to measure the width of lenses or frame lens apertures.

gauge, circumference A device used to measure the distance around the outside of a previously edged lens or a coquille for the purpose of more accurately duplicating the size of an existing lens when edging a new lens.

GCD Geometrical center distance.

generating The process of rapidly cutting the desired surface curvature onto a semifinished lens blank.

geometrical center *See* center, geometrical.

geometrical center distance *See* distance, geometrical center.

geometrically centered pattern *See* pattern, geometrically centered.

German silver *See* nickel silver.

glare control lenses *See* lenses, glare control.

glare, disability Glare that reduces visual performance and visibility and may be accompanied by discomfort.

glare, discomfort Glare that produces discomfort but does not necessarily reduce visual resolution.

glass, crown Glass lens material having an index of refraction of 1.523.

glasses, shutter Electronic glasses that can make one or both lenses alternately or simultaneously opaque for short intervals. Shutter glasses may be used in the treatment of amblyopia as an alternative to patching an eye or for sports training purposes.

glazed lens *See* lens, glazed.

glazing 1. The insertion of lenses into a spectacle frame. 2. The clogging of empty spaces between the exposed abrasive particles of an abrasive wheel, resulting in reduced grinding ability.

GOMAC system *See* system, GOMAC.

GOMAC Groupement des Opticiens du Marche Commun. (A committee of Common Market opticians formed for the purpose of establishing European optical standards.)

gradient lens *See* lens, gradient.

gradient tint *See* tint, gradient.

grayness A lens surface defect caused by incomplete polishing.

grind, bicentric Synonym for slab-off.

grinding allowance Synonym for wheel differential.

grinding, bicentric Grinding a portion of a lens so as to add a second optical center. It is often used to create vertical prism in the lower portion of one lens for the purpose of alleviating vertical imbalance at near. (Synonym: *slabbing off.*)

groover, lens The piece of equipment used to place a groove around the outer edge of a spectacle lens for the purpose of holding the lens in the frame with a nylon cord or thin metal rim.
guard arms *See* arms, pad.

H

half-eyes Frames made especially for those who need a reading correction but no correction for distance. They are constructed to sit lower on the nose than normal and have a vertical dimension that is approximately half the vertical size of normal glasses.
hand edger *See* edger, hand.
hand stone *See* edger, hand.
HAZCOM Hazard Communication Standard (HCS). The Occupational Safety and Health Administration's *Hazard Communication Standard* requires all employers to provide their employees with information and training about any possible exposure to hazardous chemicals in the workplace. Information is to be in written form and should explain workplace policy on protection from hazards.
heat treating *See* treating, heat.
height, seg The vertically measured distance from the lowest point on the lens or lens opening to the level of the top of the segment.
height, minimum fitting The minimum vertical height from the inside bevel of the lower eyewire of a spectacle frame to the center of the fitting cross of a progressive addition lens. The fitting cross is located at the pupil center. On the progressive lens, this distance corresponds to the distance from the center of the fitting cross to the near reference point (NRP).
hemianopia, homonymous A visual field defect whereby either the left half or the right half of the visual field is nonseeing in both eyes. (Synonym *homonymous hemianopsia.*)
Hide-a-Bevel Originally a trade name for an edge-grinding system that produces a shelf effect behind the bevel on thick-edged lenses. Now Hide-a-Bevel refers to this type of lens edge configuration in general.
high-index lens *See* lens, high-index.
high mass impact test *See* test, high mass impact.
high velocity impact test *See* test, high velocity impact.
hinge The part of the frame that both holds the temple to the front and allows the temple to fold closed.
hollow snipe-nosed pliers *See* pliers, hollow snipe-nosed.
homonymous hemianopia *See* hemianopia, homonymous.
horizontal alignment *See* alignment, horizontal.
horizontal midline *See* midline, horizontal.
hyperope A person with hyperopia.
hyperopia The refractive condition of the eye whereby light focuses behind the retina. Plus lenses are required to correct for hyperopia. (Synonyms: *hypermetropia*, *farsightedness.*)

I

image jump *See* jump, image.
image, real An image formed by converging light.
image shell error *See* error, image shell.
image, virtual An image formed by tracing diverging rays that are leaving an optical system back to a point from which they appear to, but do not actually originate.
imbalance, vertical A differential vertical prismatic effect between the two eyes. At near this can be induced by right and left lenses of unequal powers when the wearer drops his or her eyes below the optical centers of the lenses.
impact-rated lens *See* lens, impact-rated.
implant, intraocular lens A plastic lens placed inside the eye as a replacement for the eye's natural crystalline lens. An intraocular lens implant is commonly used to replace a crystalline lens that has lost its clarity because of a developing cataract.
impregnated wheel *See* wheel, impregnated.
index, absolute refractive The ratio of the speed of light in a vacuum to the speed of light in another medium.
index, refractive The ratio of the speed of light in a medium (such as air) to the speed of light in another medium (such as glass).
index, relative refractive The ratio obtained by dividing the speed of light in a certain medium (usually air) by its speed in another medium.
index, UV A measure of the amount of ultraviolet radiation present.
infrared Invisible rays having wavelengths longer than those at the red end of the visible spectrum yet shorter than radio waves.
inset The amount of lens decentration nasally from the boxing center of the frame's lens aperture. (Antonym: *outset.*)
inset, blank seg The horizontal distance from the blank geometrical center to the center of the multifocal segment.
inset, geometrical The lateral distance from the distance centration point to the geometrical center of the segment. (Synonym: *seg inset.*)
inset, net seg The amount of additional seg inset (or outset) required to produce a desired amount of horizontal prismatic effect at near added to the normal seg inset required by the near PD.
inset, seg The lateral distance from the major reference point to the geometrical center of the segment.
inset, total The horizontal amount the near segment must move from the boxing center to place it at the near PD (near centration distance).
intermediate The area of a trifocal lens between the distance viewing portion and the near portion.
interpupillary distance *See* distance, interpupillary.
intraocular lens implant *See* implant, intraocular lens.
invisible bifocals *See* lens, blended bifocal.
iseikonic lenses *See* lenses, iseikonic.
isocylinder line *See* line, isocylinder.
isometropia The condition described for a pair of eyes having refractive error whereby the error in both eyes is close to equal in kind and amount of refractive error. An example would be one in which both left and right eyes have refractive errors of −5.00 D. If the two errors were unequal in power, such as right −5.00 D and left −2.00 D, then the condition would be called *anisometropia.*

J

jig Also called "third hand." A jig consists of adjustable clips mounted on a base. It is used to hold a frame in place while soldering.
jump, image The sudden vertical prismatic displacement of the image of an object as the spectacle lens wearer's eye moves across the horizontal segment line of a segmented multifocal lens.

K

keyhole bridge *See* bridge, keyhole.
kevlar A nylon-based frame material.
Knapp's law *See* law, Knapp's.
knife-edge A plus lens ground to an absolute minimum thickness such that the edge of the lens is so thin that it has a knifelike sharpness to it; that is, an edge thickness of zero.

L

Lambert's law of absorption *See* law, Lambert's.
laminated lens *See* lens, laminated.
lap A tool having a curvature matching that of the curvature desired for a lens surface. The lens surface is rubbed against the face of the tool and, with the aid of pads, abrasives, and polishes, the lens surface is brought to optical quality.
lateral chromatic aberration *See* aberration, lateral chromatic.
law, Knapp's When an eye is axially ametropic, Knapp's law states that a correctly positioned, refractively correct spectacle lens will return the size of the retinal image to the same size as that produced by an emmetropic eye.
law, Lambert's Lambert's law of absorption predicts how the amount of light transmitted through a given absorbing material will change based on a change of thickness of the absorbing material.
law, Malus' A law of physics that predicts how much polarized light will be transmitted by an obliquely oriented polarizing filter.
law, Snell's An equation that predicts the refraction of light as it passes from one medium to another by stating that $n \sin i = n' \sin i'$, where n and n' are the refractive indices of the two materials, i is the angle of incidence, and i' is the angle of refraction.
layout blocker *See* blocker, layout; marker/blocker.
layout The process of preparing a lens for blocking and edging.
LEAP A 3M Company adhesive pad-blocking system.
length, datum The horizontal width of a lens or lens opening as measured along the datum line.
length, first focal For a thin lens, the distance from the lens to the first principal focus.
length, overall temple The length of a spectacle lens temple as measured from the center of the hinge barrel, around the temple bend, to the posterior end of the temple.
length, second focal For a thin lens, the distance from the lens to the second principal focus.
length-to-bend (LTB) Temple length measured from the center of the hinge barrel to the middle of the bend.

lens analyzer *See* analyzer, lens.
lens conditioner *See* conditioner, lens.
lens groover *See* groover, lens.
lens measure *See* measure, lens.
lens opening *See* opening, lens.
lens protractor *See* protractor, lens.
lens size *See* size, lens.
lens washer *See* washer, lens.
lens, achromatic A lens considered to be without chromatic aberration because selected wavelengths toward either end of the visible spectrum focus at one point. (Synonym: *achromatic doublet.*)
lens, Alvarez A lens consisting of two halves, each with a wave like surface. As the lens halves slide over each other, the power of the two parts combine, gradually changing the refractive power of the lens.
lens, aspheric A lens whose surface gradually changes in power from the center to the edge for the purpose of optimizing the optical quality of the image or reducing the thickness of the lens.
lens, aspheric lenticular A lenticular lens whose optically usable central portion has a front surface with a gradually changing radius of curvature. The farther from the center of the lens, the longer the front surface radius of curvature becomes.
lens, assistive power A variable power lens with a comparatively lower near addition. The lens is primarily for distance vision but is meant to assist a young nonpresbyope or a pre presbyope who has increased near visual needs.
lens, atoric *See* surface, atoric.
lens, best form *See* lens, corrected curve.
lens, bitoric A lens with toric surfaces on both the front and the back.
lens, blended bifocal Bifocal lenses with a segment area that is not visible to the observer. Blended bifocals are usually round-segment lenses that have the demarcation line between the distance portion and the bifocal portion smoothed away.
lens, blended myodisc A minus lens, lenticular in design, with the edges of the bowl blended so as to improve the cosmetic aspects of the lens.
lens, cement A custom-made lens that has a small near segment glued onto the distance lens.
lens, corrected curve A lens for which surface curvatures have been carefully chosen with the intent of reducing those peripheral lens aberrations that are troublesome to the spectacle lens wearer. (Synonym: *best form lens.*)
lens, cover A thin lens that is temporarily glued to the surface of a semifinished blank to protect the surface of the lens and facilitate accurate grinding, as in the case of a slab-off grind on a glass lens.
lens, degressive power An occupational progressive addition lens with near as the primary area of reference. Lens power gradually "degresses" from near up to a desired intermediate and sometimes distance power. (Synonym: *near variable focus lens.*)
lens, demo *See* coquille.
lens, double-D A multifocal lens with a flat-top bifocal-style segment in the lower portion of the lens and an inverted flat-top bifocal-style segment in the upper portion of the lens.
lens, double-segment A multifocal lens that has two segments, one in the lower and one in the upper portion of the lens.
lens, dummy *See* coquille.
lens, equiconcave A lens that is inwardly curved on both front and back surfaces with both inward curves having the same minus power.
lens, equiconvex A lens that is outwardly curved on both front and back surfaces with both outward curves having the same power.
lens, finished A spectacle lens that has been premolded to the correct power or surfaced on both front and back to the needed power and thickness. A finished lens has not been edged for a spectacle frame but is still in uncut form.
lens, Fresnel A lens made from a thin flexible plastic material having concentric rings of ever-increasing prismatic effect that duplicate the refractive effect of a powered spectacle lens.
lens, full-field aspheric An aspheric lens that continues in its asphericity all the way to the edge of the lens blank.
lens, glare control Present usage of the term denotes a lens that absorbs wavelengths toward the blue end of the spectrum in an attempt to reduce glare and increase contrast.
lens, glazed 1. A prescription or nonprescription lens mounted in a frame. 2. The thin plastic demonstration lens that comes in a pair of spectacle frames. (Synonyms: *dummy lens, coquille.*)
lens, gradient A lens having a tinted upper portion that gradually lightens toward the lower portion of the lens.
lens, hand-flattened lenticular A negative lenticular lens with the outer carrier portion produced on a hand edger and hand polished.
lens, high-index A lens with an index of refraction that is at the upper end of the range of available indices of refraction for lenses yielding a finished lens that is thinner than other lenses of the same size and power.
lens, impact-rated The ANSI Z87.1-2020 classification for safety eyewear that allows a minimum thickness of 2.0 mm when the lens material is capable of withstanding:
1. A *high mass impact test.* In this test a pointed, conical-tipped projectile, 1 inch in diameter and weighing 17.6 oz, is dropped 51.2 inches through a tube and onto the front surface of the lens.
2. A *high velocity impact test.* In this test, the lens is mounted on a special holder and must be capable of withstanding the force of a 6.35-mm (1/4-inch) diameter steel ball traveling at 150 feet/sec or a 6-mm steel ball traveling at 167 feet/sec.
3. A *penetration test.* This test consists of a weighted needle (44.2 g total weight) dropped from 50 inches.

lens, iseikonic *See* lenses, iseikonic.
lens, laminated An ophthalmic lens that is made up of more than one layer. One example is a polarized lens.
lens, lenticular A high-powered lens with the desired prescription power found only in the central portion. The outer carrier portion is shaped to reduce edge thickness and weight in minus prescriptions and center thickness and weight in plus prescriptions.
lens, meniscus A lens having a convex front surface and a concave back surface.
lens, mineral Synonym for glass lens.
lens, minus cylinder form A lens ground such that it obtains its cylinder power from a difference in surface curvature between two back surface meridians.
lens, minus lenticular A high-minus lens that is lenticular in design, having a central area containing the prescribed refractive power and a peripheral carrier with a different power chosen to reduce edge thickness.
lens, multidrop A high-plus, full-field aspheric lens in which the surface power drops rapidly as the edge of the lens is approached.
lens, multifocal A lens having a sector or sectors in which the refractive power is different from the rest of the lens, such as bifocals or trifocals.
lens, myodisc 1. Traditional definition: a high-minus lens that is lenticular in design, having a central area containing the prescribed refractive power and a peripheral carrier that is plano in power. The front curve is either plano in power or very close to plano. 2. General usage: any high-minus lens that is lenticular in design.
lens, near variable focus *See* lens, degressive power.
lens, negative lenticular A high-minus lens that has had the peripheral portion flattened for the purpose of reducing weight and edge thickness. (General usage synonym: *myodisc.*)
lens, nonimpact-rated The ANSI Z87.1-2020 classification for safety eyewear that requires a minimum thickness of 3.0 mm unless lenses are +3.00 D of power or higher in the highest plus meridian, in which case a minimum edge thickness of 2.5 mm is permissible. The impact test is less strenuous than for impact-rated lenses, only requiring that the lenses are capable of withstanding the impact of a 1-inch steel ball dropped from 50 inches. This means that glass lenses are permissible.
lens, occupational progressive A progressive addition lens that is prescribed and/or designed for specialized tasks and is not intended for full-time generalized wear.
lens, Percival form A lens design that concentrates on the elimination of power error instead of oblique astigmatism.
lens, photochromic A lens that changes its transmission characteristics when exposed to ultraviolet (UV) or short visible wavelength light.
lens, planoconcave A lens that is plano (flat) on one surface and inwardly curved on the other surface.
lens, planoconvex A lens that is plano (flat) on one surface and outwardly curved on the other surface.
lens, plus cylinder form A lens ground so that it obtains its cylinder power from a difference in surface curvature between two front surface meridians.

lens, point-focal A lens design that concentrates on the elimination of oblique astigmatism instead of power error.

lens, polarizing A lens that blocks light polarized in one plane, such as light reflected from a smooth, nondiffusing surface.

lens, power variation A lens that gradually varies in power over the lens in order to provide for different visual needs. Powers may satisfy needs for any combination of distances or accommodative needs. Examples would include progressive addition, degressive, and assistive lenses.

lens, prism segment A segment containing a different prescribed prismatic effect for near than found in the distance portion of the lens.

lens, progressive addition A lens having optics that vary in power, gradually increasing in plus (or decreasing in minus) power from the distance to near zones. Commonly referenced to the distance prescription while also correcting for intermediate and/or near powers.

lens, quadrafocal A multifocal lens that has a flat-top trifocal segment in the lower portion of the lens and an inverted flat-top bifocal-type segment in the upper portion of the lens.

lens, reverse-slab A slab-off lens that has base-down prism below the slab line instead of base-up.

lens, semifinished A lens with only one side having the desired curvature. The second side must yet be surfaced to bring the lens to its desired power and thickness.

lens, single-vision A lens with the same sphere and/or cylinder power throughout the whole lens, as distinguished from a multifocal lens.

lens, size *See* lenses, iseikonic.

lens, spheric lenticular A lenticular lens in which the optically usable central portion has a front surface that does not vary in curvature but is entirely spherical.

lens, stock A lens that is premade, does not have to be custom surfaced, and is ready to edge.

lens, uncut A lens that has been surfaced on both sides but not yet edged for a frame.

lens, X-Chrom A red contact lens worn on only one eye in an attempt to improve color discrimination between some colors for certain red-green color defectives.

lens, Younger seamless Trade name for a blended bifocal designed by Younger Optics.

lenses, iseikonic A lens pair with their curvatures and thicknesses specially chosen to produce a difference in image magnification between the right and left eyes for the purpose of correcting image size differences between right and left eyes. Also known as *size lenses*.

lenslet Miniature lenses. Lenslets may be applied to the mid-periphery of a spectacle lens close together, in plus power, and in significant quantities for the purpose of reducing the progression of myopia.

lensmaker's formula *See* formula, lensmaker's.

lensmeter The instrument used for finding power and prism in spectacle lenses. (Synonyms: *focimeter, vertometer, lensometer.*)

Lensometer A trade name for a type of lensmeter (focimeter).

lenticular A high-powered lens with the desired prescription power found only in the central portion. The outer carrier portion is ground so as to reduce edge thickness and weight in minus prescriptions and center thickness and weight in plus prescriptions.

lenticular lens *See* lenticular or lens, lenticular.

lenticular, aspheric A lenticular lens whose optically usable central portion has a front surface with a changing radius of curvature.

lenticular, hand-flattened A negative lenticular lens with the lenticular portion produced on a hand edger and hand polished.

lenticular, negative A high-minus lens that has had the peripheral portion flattened for the purpose of reducing weight and edge thickness. (Synonym: *myodisc.*)

lenticular, spheric A lenticular lens in which the optically usable central portion has a front surface that does not vary in curvature but is entirely spherical.

let-back That angle an open temple forms in relationship to the front of the frame (also called *open temple spread*).

level, reading A synonym for reading depth. *See* depth, reading.

library temple *See* temple, library.

light box *See* box, light.

line, cutting A term that was used for the 180-degree line that used to be hand marked or stamped on a lens after it had been properly positioned for cylinder axis orientation and decentration. It was used as a reference line in blocking and edging a lens.

line, datum A line parallel to and halfway between horizontal bordering lines tangent to the lowest and highest edges of the edged lens. (Synonyms: *horizontal midline, 180-degree line.*)

line, isocylinder One of the lines on a contour plot of a progressive addition lens diagram denoting the location of unwanted cylinder of a given dioptric power.

line, mounting 1. The horizontal reference line that intersects the mechanical center of a lens pattern. 2. Historical usage: On metal or rimless spectacles, the line that passes through the points at which the pad arms are attached and that serves as a line of reference for horizontal alignment.

line, 180-degree A synonym for horizontal midline.

liner, figure-8 A liner that fits into the top eyewire channel of some nylon cord frames.

longitudinal chromatic aberration *See* aberration, longitudinal chromatic.

LTB The length-to-bend measure of a frame temple.

M

maculopathy, age-related A degeneration of the sensitive macular area of the retina. Also called *macular degeneration*.

magnification difference *See* difference, magnification.

magnification, relative spectacle (RSM) The amount of magnification produced by a given eye relative to that of a standard eye.

magnification, spectacle (SM) The difference in the size of an image seen by a spectacle-lens–corrected eye compared with the size of the image seen by the same eye without a spectacle lens correction.

Malus' law *See* law, Malus'.

major meridian *See* meridian, principal.

major reference point *See* point, major reference.

marking, alignment reference (ARM) The semivisible markings found on a progressive addition lens surface that are used to indicate the 180-degree horizontal. They may be visibly marked with a marking pen so that, when placed on the lens manufacturer's centration chart, the other expected locations such as the fitting cross, distance and near reference locations, and prism reference points may be found.

marginal astigmatism *See* astigmatism, oblique.

marker An older-style centering device used to accurately position a lens and stamp it with the horizontal and vertical reference lines used in lens blocking.

marker/blocker A device used to accurately position a lens and then either (1) stamp it with horizontal and vertical reference lines for use in later lens blocking or (2) block it directly while still in the device.

material safety and data sheet A single sheet of paper containing information about a potentially hazardous chemical found in the workplace. MSDS sheets should include physical and chemical characteristics, known acute and chronic health effects, exposure limits, precautionary measures, and emergency and first-aid procedures.

MBL Minimum between lenses.

MBS Minimum blank size. *See* size, minimum blank.

mean dispersion *See* dispersion, mean.

measure, lens *See* clock, lens.

memory plastic A plastic material that can be bent or twisted and still return to its original shape.

meniscus lens *See* lens, meniscus.

meridian, axis The meridian of least power of a cylinder or spherocylinder lens; for a minus cylinder, the least minus meridian, and for a plus cylinder, the least plus meridian.

meridian, major Synonym for principal meridian. *See* meridian, principal.

meridian, power The meridian of maximum power of a cylinder or spherocylinder lens; for a minus cylinder, the most minus meridian, and for a plus cylinder, the most plus meridian.

meridian, principal One of two meridians in a cylinder or spherocylinder lens or a toric lens surface. These meridians are normally 90 degrees apart and correspond to the maximum and minimum powers in the lens.

metal-bonded wheel *See* wheel, metal bonded.

metal saddle bridge *See* bridge, metal saddle.

metalized coating *See* coating, metalized.

middatum depth *See* depth, middatum.

midline, horizontal In the boxing system of lens measurement, the horizontal line halfway between the upper and lower horizontal lines bordering the lens shape. (Synonym: *180-degree reference line.*)

minibevel A lens edge configuration that has a bevel and an angled ledge.
minimum between lenses The datum system equivalent of the boxing system's distance between lenses (DBL).
minimum fitting height *See* height, minimum fitting.
minus add bifocal *See* bifocal, minus add.
minus cylinder form *See* form, minus cylinder.
minus cylinder form lens *See* lens, minus cylinder form.
minus lenticular lens *See* lens, minus lenticular.
mirror coating *See* coating, mirror.
Monel A whitish, pliable, nicely-polishing metal frame material that is made from nickel, copper, and iron; it also contains traces of other elements.
monochromatic aberration *See* aberration, monochromatic.
monocular PD *See* PD, monocular.
monovision A refractive correction in which one eye is used for distance and the other eye is used for near viewing.
mounting 1. The name for a spectacle lens frame when the lenses are held in place without the aid of an eyewire as with rimless or semirimless mountings. 2. The attaching of lenses to a rimless or semirimless spectacle frame.
mounting line *See* line, mounting.
mounting, Balgrip A mounting (frame) that secures the lens in place with clips attached to a bar of tensile steel that fits into a nasal and a temporal slot on each side of the lens.
mounting, Numont A lens mounting that holds the lenses in place only at their nasal edge. The lenses are attached at the bridge area, and the temples are attached to a metal arm that extends along the posterior surface temporally. Thus each lens has only one point of attachment.
mounting, rimless A mounting that holds the lenses in place by some method other than eyewires or nylon cords. Usually the method of mounting is by screws or posts through the lenses. (Synonym: *three-piece mounting.*)
mounting, semirimless Mountings similar to rimless mounting but with the addition of a metal reinforcing arm, which follows the upper posterior surface of the lens and joins the centerpiece of the frame to the endpiece. (Some refer to nylon cord frames as being semirimless.)
mounting, 3-piece *See* mounting, rimless.
mounting, Wils-Edge A lens mounting (frame) that secures the lens in place by means of a grooved arm that grips the top of the lens.
MRP An abbreviation for major reference point. *See* point, major reference.
MSDS Abbreviation for a material safety and data sheet.
multidrop lens *See* lens, multidrop.
multifocal A lens having a sector or sectors in which the refractive power is different from the rest of the lens, such as bifocals or trifocals.
multifocals, fused Glass multifocal lenses in which the segment cannot be felt by running a finger across the border of the segment because it is fused into the distance portion of the lens.
multifocals, occupational Any segmented or progressive addition lens that is designed or chosen by careful forethought and positioned for a specialized work or viewing situation.
multifocals, one-piece One-piece multifocal lenses are made from only one lens material that has one specific index of refraction. Thus, any change in lens segment power is the result of a change in segment surface curvature compared to the curvature of the main portion of the lens. Segment power change is not the result of using a different segment material with a higher refractive index.
multifocals, segmented Multifocal lenses having a visible, clearly demarcated bifocal or trifocal area.
myodisc *See* lens, myodisc.
myope A person with myopia.
myopia The refractive condition of the eye whereby light focuses in front of the retina. Minus lenses correct for myopia. (Synonym: *nearsightedness.*)

N

n An abbreviation for refractive index.
nasal The side of a lens or part of the frame that is toward the nose (inner edge).
nasal add *See* add, nasal.
nasal cut *See* cut, nasal.
NBC The abbreviation for nominal base curve.
near power *See* power, near.
near prescription The net lens power resulting from the combination of the add power and the distance power.
near reference point *See* point, near reference.
nearsightedness *See* myopia.
net seg inset *See* inset, net seg.
neutralize To determine the refractive power of a lens. Most often this is done with the aid of a lensmeter.
neutralizer A solution used to reduce the color in or remove the color from a previously tinted lens.
nickel silver A whitish-appearing metal frame material containing more than 50% copper, 25% nickel, and the rest zinc. (Synonym: *German silver.*)
nominal base curve *See* curve, nominal base.
nonimpact-rated lens *See* lens, nonimpact rated.
normal A line perpendicular to a reflecting or refracting surface at the point of incidence of an incoming ray of light.
nose pads Plastic pieces that rest on the nose to support the frame.
notch filter *See* filter, notch.
NRP An abbreviation for near reference point. *See* point, near reference.
number, set The compensating number used with a pattern to arrive at a compensated eyesize setting for an edger requiring a physical pattern.
Numont mounting *See* mounting, Numont.
Numont pliers *See* pliers, Numont.
nystagmus A condition characterized by a constant, involuntary back-and-forth movement of the eyes.

O

oblique astigmatic error *See* error, oblique astigmatic.
oblique astigmatism *See* astigmatism, oblique.
OC An abbreviation for optical center. *See* center, optical.
occupational multifocals *See* multifocals, occupational.
Occupational Safety and Health Administration The U.S. government agency responsible for setting workplace safety policy and ensuring worker safety.
OD Latin, oculus dexter (right eye).
OLA Abbreviation for the Optical Laboratories Association.
one-piece multifocals *See* multifocals, one-piece.
open temple spread *See* spread, open temple.
opening, lens The portion of the spectacle frame that accepts the spectacle lens. (Synonym: *lens aperture.*)
OPL An abbreviation for occupational progressive lens. *See* lens, occupational progressive.
optical axis *See* axis, optical.
optical bleaching *See* bleaching, optical.
optical center *See* center, optical.
Optical Laboratories Association A professional association of optical laboratories.
optically centered pattern *See* pattern, optically centered.
Optyl The trade name for an epoxy resin material used to make spectacle frames.
OS Latin, oculus sinister (left eye).
OSHA Occupational Safety and Health Administration.
outset The amount of lens decentration temporally from the boxing center of the frame's lens aperture. (Antonym: *inset.*)
overall temple length *See* length, overall temple.

P

pad arms *See* arms, pad.
pad-adjusting pliers *See* pliers, pad-adjusting.
pad bridge *See* bridge, pad.
pads, buildup Small nose pad-shaped pieces of plastic applied to the frame bridge and used to alter the fit of the bridge.
PAL An abbreviation for progressive addition lens. *See* lens, progressive addition.
Panoptik *See* bifocal, Panoptik.
pantoscopic angle or tilt *See* angle, pantoscopic.
pantoscopic angling pliers *See* pliers, pantoscopic angling.
parallax The apparent change in position of an object as the result of a change in viewing angle.
paraxial rays *See* rays, paraxial.
pattern difference *See* difference, pattern.
pattern A plastic or metal piece having the same shape as the lens aperture for a given frame. Used in lens edging as a guide for shaping the lens to fit the frame.
patterned edger *See* edger, patterned.
patternless edger *See* edger, patternless.
PD An abbreviation for interpupillary distance. (*See* distance, interpupillary.)
PD, binocular The measured distance from the center of one pupil to the center of the other pupil without regard to how each eye may vary in its distance from the center of the bridge of the frame.
PD, distance The wearer's interpupillary distance specified for a situation equivalent to when the wearer is viewing a distant object.

PD, frame Synonym for geometrical center distance or distance between centers.

PD, monocular The distance from the center of the frame bridge to the center of the wearer's pupil measured for each eye separately.

PD, near The interpupillary distance as specified for a near viewing situation.

peening The act of putting a rivetlike head on the end of the posts (rivets) on so-called "riveted hinges" or on the tip of a frame screw.

peening pliers *See* pliers, peening.

penetration test *See* test, penetration.

Percival form lens *See* lens, Percival form.

peripheral rays *See* rays, peripheral.

phoria The direction of the line of sight of one eye with reference to that of the partner eye when fusion is interrupted as when one eye is covered.

photochromic lens *See* lens, photochromic.

photometer An instrument for measuring brightness. When used with lenses, the percent transmission of the lens as measured in a given spectral area or areas.

physiological aniseikonia *See* aniseikonia, physiological.

pillar file *See* file, pillar.

pincushion distortion *See* distortion, pincushion.

planes, variant A form of vertical misalignment of a spectacle frame in which the lens planes are out of coplanar alignment (one lens is farther forward than the other).

plano (pl) A lens or lens surface having zero refracting power.

planoconcave lens *See* lens, planoconcave.

planoconvex lens *See* lens, planoconvex.

pliers, bridge-narrowing Used to narrow the bridge of a plastic frame.

pliers, bridge-widening Used to widen the bridge of a plastic frame.

pliers, chipping Pliers that were primarily used to chip or break away the outer portions of an uncut or semifinished glass lens to either reduce its size or bring it into the rough shape needed to approximate the finished shape.

pliers, endpiece angling Pliers used for bending the hinge of a frame in order to change either the pantoscopic angle or the temple fold angle.

pliers, eyewire-forming Pliers with horizontally curved jaws used to shape the upper and/or lower eyewires of a metal frame to match the meniscus curve of the edged lens.

pliers, fingerpiece Pliers used for adjustment of the temple-fold angle of plastic frames. Fingerpiece pliers have parallel jaws and were originally designed for adjusting fingerpiece mountings. Also called *Fits-U pliers.*

pliers, hollow snipe-nosed Thin-nosed pliers with a hollowed-out central jaw area.

pliers, Numont Holding pliers specially designed for use with Numont mountings.

pliers, pad-adjusting These pliers have one cupped jaw to conform to the face portion of an adjustable nose pad; the other jaw is shaped to allow the back of the pad to be held securely while being angled.

pliers, peening Pliers with a round, cupped edge for placing a rivetlike head on the end of a screw.

pliers, punch Pliers with a fine, rounded, rodlike projection that is placed against the filed end of the rivet to punch it out of a plastic frame. Also used to punch out damaged frame screws.

pliers, rimless adjusting Pliers used to grasp and hold a rimless mounting at the point of attachment between lens and mounting.

pliers, snipe-nosed Pliers that taper to a small tip on both jaws, allowing use in tight places. Often used in the adjustment of pad arms.

pliers, square-round Used to adjust pad arms, these pliers have a small round section on one jaw and a squared off section on the other.

pliers, strapping Pliers having two flat jaws. One jaw extends beyond the other and then overlaps it. Used to adjust straps of antique rimless or semirimless mountings.

plot, contour A line diagram used to plot the areas of either unwanted cylinder or spherical equivalent power over the viewing areas of a progressive addition lens.

plus cylinder form *See* form, plus cylinder.

plus cylinder form lens *See* lens, plus-cylinder form.

point An optical laboratory term for one-tenth of a millimeter of lens thickness.

point, distance centration The British equivalent of the major reference point.

point, distance reference (DRP) That point on a lens where, according to the manufacturer, the distance power is to be measured. Distance power consists of sphere, cylinder, and axis. The DRP may not correspond to the prism reference point, as with progressive addition lenses.

point, focal A point to or from which light rays converge or diverge.

point-focal lens *See* lens, point-focal.

point, major reference (MRP) The point on a lens where the prism equals that called for by the prescription.

point, near reference (NRP) That point on a progressive addition lens where, according to the manufacturer, the near power of the lens is to be measured.

point, prism reference (PRP) The point on a lens where prism power is to be verified. Also referred to as the *major reference point (MRP).* For progressive addition lenses, the term *PRP* is used instead of *MRP.*

polariscope *See* colmascope.

polarizing lens *See* lens, polarizing.

polyamide A strong, nylon-based frame material that allows a frame to be made thinner and lighter.

polycarbonate A 1.586-index lens material known for its strength.

position of wear Referencing the location and orientation of the spectacle frames and lenses relative to the wearer's eyes. Position of wear lenses are assumed to be power-corrected for such measurements as vertex distance, pantoscopic tilt, and wrap angle that might not ordinarily be specified. *See also* power, as-worn.

power boost *See* boost, power.

power cross *See* cross, power.

power factor *See* factor, power.

power meridian *See* meridian, power.

power variation lens *See* lens, power variation.

power, actual Synonym for true power.

power, approximate Synonym for nominal power.

power, as-worn The power of a spectacle lens that has been adjusted from the ordered prescription by the optical laboratory to compensate for measured factors such as vertex distance, frame face form (wrap angle), and pantoscopic tilt. These changes may alter the sphere and cylinder powers, as well as the cylinder axis, and sometimes include a prismatic component. *See also* position of wear.

power, back vertex The reciprocal of the distance in air from the rear surface of the lens to the second principal focus. Used when measuring spectacle lenses.

power, chromatic *See* aberration, lateral chromatic.

power, compensated 1. The new lens power needed in order to maintain the intended lens prescription when the spectacle lenses are worn at a vertex distance different from the vertex distance used during refraction. The compensated lens power will maintain the same focal point location as that found during refraction. 2. In surfacing, back vertex power that has been converted to a 1.53 index frame of reference. Used for the purpose of finding a 1.53 index–referenced tool curve for a lens with a different index of refraction.

power, cylinder The difference in refractive powers between the two major meridians of a cylinder or spherocylinder lens.

power, dispersive The following quantity $\frac{n_F - n_C}{n_D - 1}$ used for quantifying chromatic aberration of a given material. Dispersive power is abbreviated as the Greek letter omega (ω).

power, effective The vergence power of a lens at a reference plane other than the reference plane occupied by the lens itself.

power, focal A measure of the ability of a lens or lens surface to change the vergence of entering light rays.

power, front vertex The reciprocal of the distance in air from the front surface of a lens to the first principal focus.

power, near The sum of the distance power and the near add.

power, nominal An estimate of total lens power calculated as the sum of front and back surface powers without regard to lens thickness (not to be confused with nominal base curve). (Synonym: *approximate power.*)

power, prism The amount light is displaced in centimeters at a distance 1 m away from the lens or prism.

power, refractive The dioptric value that accurately describes the ability of a lens or lens surface to converge or diverge light. For a lens surface in air, the refractive power is expressed as $F = \frac{n-1}{r}$ where n is the refractive index of the lens material and r is the radius of the surface expressed in meters.

power, true The 1.53 index–referenced curvature of a lens surface. True lens surface power is found by using either a lens clock or

a sagometer (sag gauge) that is 1.53 index–referenced.

power, verification The power that should be used to verify the accuracy of the ordered prescription. When no changes are made by the dispenser or lens manufacturer to allow for new vertex distances, or frame wrap or tilt, then the prescribed powers are the verification powers. When such changes are made, then those compensated powers become the powers used for verification.

Prentice's rule *See* rule, Prentice's.

presbyopia The refractive state in which the crystalline lens within the eye becomes nonelastic as a result of the aging process.

pressure, lateral The pressure of the temples against the sides of the head just above the ears.

principal meridian *See* meridian, principal.

prism Two nonparallel, transparent surfaces that cause entering light to change direction as it exits.

prism axis *See* axis, prism.

prism diopter *See* diopter, prism.

prism power *See* power, prism.

prism reference point (PRP) *See* point, prism reference.

prism thinning *See* thinning, prism.

prism, Fresnel A prism made from thin flexible material and consisting of small rows of equal-powered prisms resulting in the same optical effect as that of a conventional ophthalmic prism.

prism, prescribed Prism in an ophthalmic lens prescription that has been called for by the prescribing physician. (Synonym: *Rx prism.*)

prism, Risley's An application of obliquely crossed prisms in which two equally powered prisms are placed one on top of another. The two prisms can be gradually rotated from where their bases are oriented in the same direction to where their bases are in completely opposite directions. This results in variable prism power. Also called *rotary prism.*

prism, yoked 1. Vertical prism of equal value ground on both right and left lenses of a progressive or Franklin-style lens for the purpose of reducing lens thickness. 2. Prism of equal power placed on both lenses yielding a net binocular prismatic effect of zero. Used for the purpose of displacing the image of an object in a desired direction. Both may be base right, both base left, both base up, or both base down.

progressive addition lens *See* lens, progressive addition.

progressive corridor *See* corridor, progressive.

propionate The common name for the frame material cellulose acetopropionate. Propionate has many of the same characteristics as cellulose acetate and is better suited for injection molding.

protractor, lens A millimeter grid on a 360-degree protractor that has been used in the lens centration process for both surfacing and finishing.

PRP An abbreviation for prism reference point. *See* point, prism reference.

pseudophake A person who has had their crystalline lens removed and replaced with an intraocular lens implant.

pterygium A growth of tissue that begins on the white of the eye and extends onto the cornea.

punch pliers *See* pliers, punch.

Q

quadrafocal *See* lens, quadrafocal.

R

radial astigmatism *See* astigmatism, oblique.

raise, seg 1. The vertical distance from the major reference point (MRP) to the top of the seg when the seg top is higher than the MRP. 2. The vertical distance from the horizontal midline of the edged lens to the top of the seg when the seg top is higher than the horizontal midline (laboratory usage). (Antonym: *seg drop.*)

rat-tail file *See* file, rat-tail.

rays, paraxial Those rays of light that pass through the central area of the lens.

rays, peripheral Those rays of light that enter the non-central areas of the lens.

R-compensated segs *See* segs, R-compensated.

reading center *See* center, reading.

reading depth *See* depth, reading.

reading level *See* level, reading.

real image *See* image, real.

Rede-Rite bifocal *See* bifocal, minus add.

reduced thickness *See* thickness, reduced.

reference point, distance (DRP) *See* point, distance reference.

reference point, near (NRP) *See* point, near reference.

reference point, prism (PRP) *See* point, prism reference.

reflex color *See* color, reflex.

refraction 1. The bending of light by a lens or optical system. 2. The process of determining the needed power of a prescription lens for an individual.

refractive ametropia *See* ametropia, refractive.

refractive index *See* index, refractive.

refractive power *See* power, refractive.

relative refractive index *See* index, relative refractive.

relative spectacle magnification *See* magnification, relative spectacle.

resolving (of prism) The process of expressing a single prism as two prisms for which the horizontal and vertical base directions are perpendicular to each other but for which the combined effect equals that of the original prism.

retroscopic angle or tilt *See* angle, retroscopic.

reverse-slab lens *See* lens, reverse-slab.

ribbon bifocal *See* bifocal, ribbon.

ribbon file *See* file, slotting.

riding-bow temple *See* temple, riding-bow.

riffler file *See* file, riffler.

rim *See* eyewire.

rimless Having to do with frames (mountings) that hold lenses in place by some method other than eyewires. Most rimless mountings have two points of attachment per lens.

rimless mounting *See* mounting, rimless.

Rimway mounting *See* mounting, semirimless.

Risley's prism *See* prism, Risley's.

rolled edge *See* edge, rolled.

rolling A pulling of the plastic rim of the frame such that it covers less of the front of the lens bevel than back or vice versa.

round-seg bifocal *See* bifocal, round-seg.

rule, Prentice's A rule that states that the decentration of a lens in centimeters times the power of the lens is equal to the prismatic effect caused by this decentration. Expressed as an equation, this is $\Delta = cF$.

rule, three-quarter The three-quarter rule states that for every diopter of dioptric demand, the optical center of each reading lens or the geometrical center of each bifocal addition should be inset approximately 0.75 (three-quarter) mm.

Rx prism *See* prism, prescribed.

S

saddle bridge *See* bridge, saddle.

safety bevel *See* bevel, safety.

safety eyewear *See* eyewear, safety.

sag A synonym or abbreviation for sagittal depth. *See* also depth, sagittal.

sagittal depth *See* depth, sagittal.

scotoma A nonseeing area or an area of depressed sensitivity in a person's visual field.

scotoma, apical When a prism displaces the image of an object, it is displaced toward the apex of the prism. When a prism is found in one section of a lens, there will be an area of the visual field that disappears. In the case of vertical prism, a person viewed through the lens with the prism may appear to have their head directly on their body, with no neck. The neck is in the area of the apical scotoma. For horizontal prism, small objects may seem to disappear then reappear when the lens wearer turns his or her head.

scratch A furrowed-out line that has jagged edges.

screw extractor *See* extractor, screw.

second focal length *See* length, second focal.

second principal focus *See* focus, second principal.

seg *See* segment.

seg clock *See* clock, seg.

seg depth *See* depth, seg.

seg drop *See* drop, seg.

seg height *See* height, seg.

seg inset *See* inset, seg.

seg optical center *See* center, seg optical.

seg width *See* width, seg.

segment (seg) An area of a spectacle lens with power differing from that of the main portion.

segment, prism *See* lens, prism segment.

segmented multifocals *See* multifocals, segmented.

segs, dissimilar A method of correcting vertical imbalance at near that uses different bifocal segment styles for the right and left eyes.

segs, R-compensated A method for correcting vertical imbalance at near that uses ribbon-style bifocal segments that have been modified so that the segment optical center for one lens is higher in one segment and lower in the other.

semidiameter Diameter divided by two. In ophthalmic optics, semidiameter refers to half of the chord for the arc of a given surface and is used in calculating the sagittal depth of the surface.

semifinished blank *See* blank, semifinished.

semirimless mountings *See* mountings, semirimless.

semisaddle bridge *See* bridge, semisaddle.

set number *See* number, set.
shaft The portion of the temple between the butt end and the bend.
shank *See* shaft.
shape memory alloy (SMA) The name applied to a titanium alloy made with 40% to 50% titanium and the rest nickel. It is very flexible and returns to its original shape. (Synonym: *memory metal.*)
shell frame *See* frame, shell.
shield On a plastic frame with rivet hinges, the metal piece to which rivets are attached to hold the hinge in place. Some frames may have decorative shields without rivets.
shields, side Protective shields attached to the spectacle frame in the outer, temporal areas to protect the eyes from hazards approaching from the side.
shoe That part of the strap area of an antique-type rimless mounting that contacts the edge of the lens, bracing it. Also called *shoulder* or *collar.*
shop, back Synonym for surfacing laboratory.
shop, front Synonym for finishing or edging laboratory.
shoulder *See* shoe.
shutter glasses *See* glasses, shutter.
side shields *See* shields, side.
sine For a right triangle, the ratio of the side opposite the angle considered, to the hypotenuse: $\text{Sine} = \frac{\text{Opposite}}{\text{Hypotenuse}}$.
sine-squared formula *See* formula, sine-squared.
single-vision lens *See* lens, single-vision.
size lenses *See* lenses, iseikonic.
size, lens In the boxing system, the A dimension of a lens or lens opening.
size, minimum blank The smallest lens blank that can be used for a given prescription lens and frame combination and still cover the lens aperture (lens opening) of the frame.
sizer A frame chassis or frame front used exclusively by the optical laboratory for checking edged lens size accuracy when lenses only are ordered.
skewed bridge *See* bridge, skewed.
skull temple *See* temple, skull.
slab-off That portion of a lens that is surfaced with prism so as to create an optical center at a location different from that of the distance portion of the lens. It is usually used to create vertical prism in the lower portion of one lens for the purpose of alleviating vertical imbalance between the two eyes at near.
sleek A furrowed-out line on a lens that resembles a scratch, but its edges are smooth instead of jagged.
slotting file *See* file, slotting.
smoothing, edge The process of bringing the bevel surfaces of an edged lens to a finer, smoother finish.
snap, cold To cold snap a lens into place is to insert that lens into a frame without first heating the frame.
Snell's law *See* law, Snell's.
snipe-nosed pliers *See* pliers, snipe-nosed.
solid tint *See* tint, solid.
space eikonometer *See* eikonometer, space.
spectacle magnification *See* magnification, spectacle.
spectrophotometer A device used to measure the transmission of each wavelength of light across the spectrum.
sphere (sph) A lens having a single refractive power in all meridians.
spheric lenticular *See* lenticular, spheric.
spherical aberration *See* aberration, spherical.
spherical equivalent *See* equivalent, spherical.
spherical surface *See* surface, spherical.
spherocylinder The combination of sphere and cylinder powers into a single lens.
splay angle *See* angle, splay.
sports eyewear *See* eyewear, sports.
spotting The placing of spots on a lens with a lensmeter in such a manner that the lens will be oriented correctly for axis and positioned for major reference point and horizontal meridian locations when being verified or when being blocked and edged.
spread, open temple That angle an open temple forms in relationship to the front of the frame (also called *let-back*).
square-round pliers *See* pliers, square-round.
SRC An abbreviation for scratch-resistant coating.
staking tool A multipurpose tool used to apply concentrated force to parts of a frame, such as when punching out damaged hinge rivets.
standard alignment *See* alignment, standard.
stars Microchips in a lens at the location where the lens surface and the lens edge meet.
stock lens *See* lens, stock.
stock, lens 1. An inventory of lenses. 2. The material from which a semifinished blank is made. When the surface of a lens is ground, *lens stock* is removed from the semifinished blank to bring the lens to its needed thickness.
stone 1. An abrasive grinding wheel. 2. To sharpen the cutting ability of a grinding wheel by honing it with an abrasive stick.
stone, hand *See* edger, hand.
strabismus The condition whereby one eye is pointed in a different direction than the other eye.
strap An old-style mechanism for holding drilled lenses in an antique rimless or semirimless mounting.
strapping pliers *See* pliers, strapping.
stria A streak seen in a lens caused by a difference in the refractive index in the material. The streak causes a distortion in the object viewed and is not a physical streak, such as a mark on or in the lens. (The plural of stria is striae.)
surface, aspheric A surface that changes uniformly in radius of curvature in every meridian from the center to the periphery of the lens. Normally the radius of curvature gradually increases in length in order to reduce aberration in the periphery of the lens.
surface, atoric A lens surface with a cylinder component whose surface gradually changes in power beginning from the center to the edge. Each of the two major meridians changes in power by differing amounts based on the cylinder power of the lens. This is done for the purpose of optimizing optical quality in the periphery of the lens in both meridians.
surface, plano A flat surface with zero refractive power. *See also* plano (pl).
surface, spherical A lens surface with one radius of curvature in every meridian of the lens.
surfacing The process of creating the prescribed refractive power, prism, and major reference point location on a lens by generating the required curves and bringing the surface to a polished state.
system, boxing A system of lens measurement based on the enclosure of a lens by horizontal and vertical tangents to form a box or rectangle.
system, datum A system of lens measurement that defines the lens or eyesize as being the width of the lens along the datum line and the bridge size as the width of the bridge at the level of the datum line.

T

tables, sag A set of tables used for finding sagittal depth when surface power and lens diameter are known.
tables, surfacing Tables supplied by a lens manufacturer for the purpose of helping the surfacing laboratory accurately determine the tool curves and lens thicknesses needed to grind lenses to the specified back vertex power. Surfacing tables are now largely replaced by computer software programs.
tangent For a right triangle, the ratio of the side opposite the angle considered to the side adjacent: $\text{Tangent} = \frac{\text{Opposite}}{\text{Adjacent}}$.
tap Consists of a chuck on a handle in which threaders of varying size may be placed. It is used to restore threading that has been damaged.
tempering, chemical The process of increasing the impact resistance of glass lenses by immersing them in a bath of molten salt. (Synonyms: *chemtempering, chem hardening.*)
temple The part of a pair of spectacles that attaches to the frame front and hooks over the ears to hold spectacles in place.
temple, cable Cable temples are of metal construction with the curl, or posterior portion, constructed from a flexible, coiled cable. The behind-the-ear portion of the temple follows the crotch of the ear where ear and the head meet and extends to the level of the earlobe. (Old synonym: *Relaxo temple.*)
temple, comfort cable *See* temple, cable.
temple, convertible Temples that are straight through their entire length but are designed to be bent down to take on the form of a skull temple.
temple, library Typically a wide type of spectacle frame temple that is practically straight and holds the glasses on primarily by pressure against the side of the head.
temple, riding-bow Plastic temples that are thin and round behind the ear. The behind-the-ear portion curves around the ear, following the crotch of the ear where ear and the head meet. They extend to the level of the earlobe. They

often are used in children's and safety frames and are the plastic version of a metal comfort cable temple.

temple, skull The type of spectacle frame temple that bends down behind the ear and is adjusted to follow the contour of the skull, resting evenly against it.

temple-fold angle *See* angle, temple-fold.

temporal The areas of a lens or frame that are closest to the sides of the head.

test, drop-ball A pass/fail test to determine impact resistance of ophthalmic lenses whereby either a $^{5}/_{8}$- or 1-inch steel ball is dropped onto the front surface of the lens from a height of 50 inches.

test, flat surface touch A test for temple parallelism in which the spectacles are positioned upside down on a flat surface with temples open.

test, high mass impact A pointed, conical-tipped projectile weighing 17.6 oz is dropped from 51.2 inches through a tube and onto a safety frame or safety lens, depending upon which is being tested. The lens must not break, nor shall it come out of the frame.

test, high-velocity impact This test for safety frames and lenses simulates a high-velocity, low-mass object. In the high-velocity impact test, a 6.35 mm (1/4 inch) diameter steel ball traveling at 150 feet/sec or a 6 mm steel ball traveling at 167 feet/sec is directed at the lens or the frame with lenses in place, depending upon which is being tested.

test, penetration This test consists of a weighted needle (44.2 g total weight) dropped on the front surface of a safety lens from a height of 50 inches.

thermal bleaching *See* bleaching, thermal.

thermoelastic A term used to describe a material that will bend when heated and formed by hand but will return to its original shape on its own when reheated. It is said to have "plastic memory."

thermoplastic A term used to describe a material that will bend when heated and formed by hand but does not return to its original shape when reheated because it does not have a "plastic memory."

thickness, reduced The thickness of an optical medium divided by its refractive index.

thinning, prism Thinning of a progressive addition lens produced by nonprescribed amounts of vertical prism applied to both right and left lenses equal in base direction and amount. The purpose is to produce a lens that is thinner and lighter in weight. Prism thinning is usually base down in direction and may also be applied to some segmented multifocal lenses such as one-piece Franklin (Executive)-style lenses to achieve overall lens thinning.

three-quarter rule *See* rule, three-quarter.

tint, double gradient A lens tint that has two colors, one at the top and a second at the bottom. The color at the top is darkest at the top and fades out toward the middle of the lens. The color at the bottom is most intense at the bottom and lightens toward the middle.

tint, gradient The variation in light transmission of a lens from low transmission (dark) to high transmission (light) from one area of the lens to another. Usually the lens is dark at the top and lightens toward the bottom.

tint, solid A tint that has the same color and light transmission over the entire lens.

tint, triple gradient A lens with three colors. The color at the top is darkest at the top and fades out toward the middle of the lens. The color at the bottom is most intense at the bottom and lightens toward the middle. The third color is in the middle of the lens.

tongue *See* ear.

tool, lap A tool used for fining and polishing lens surfaces. The tool used must have a surface identical in curvature to that of the lens for which it is to be used when compensated for lap pad tool thicknesses. If the lens surface is convex, the tool must be concave. Both must have the same curvature.

tool power *See* power, true. (Synonym: *true power*.)

toric A surface having separate curves that are at right angles to one another.

toric base curve *See* curve, toric base.

toric transposition *See* transposition, toric.

total inset *See* inset, total.

touch, four-point A check for vertical alignment carried out by placing a straight edge so that its edge goes across the inside of the entire front of the spectacles.

tracer, frame An instrument used to physically trace the inside groove of a frame's lens opening or the outside edge of a lens for the purpose of creating a digitized shape. That shape is then transmitted to a patternless edger so that the shape may be duplicated when the lens is edged.

Transitions A trade name for a brand of plastic photochromic lenses.

transmission The amount of light passing on through a lens and out the back surface compared with the amount of light incident upon the first surface. This comparative amount is most often expressed as a transmission factor or as a percentage.

transmission factor *See* factor, transmission.

transposition, toric The process of transposing a prescription from the form in which it is written to another form, such as from a plus to a minus cylinder form.

treating, heat The process of hardening a glass lens by first heating it in a kiln, then quickly cooling by blowing forced air against both front and back surfaces. (Synonyms: *air hardening, heat hardening, heat tempering*.)

trifocals Lenses having three areas of viewing, each with its own focal power. Usually the upper portion is for distance viewing, the lower for near, and the middle or intermediate portion for viewing intermediate distances.

triple gradient tint *See* tint, triple gradient.

Trivex The brand name for a PPG Industries plastic lens material known for its high impact resistance and ability to be processed in a manner similar to that of other plastic lenses.

true 1. To bring a pair of glasses into a position of correct alignment. 2. To reshape the cutting surface of a worn grinding wheel so that it cuts at the angles and in the manner originally intended. 3. In surfacing when using a hand pan, a step following roughing and smoothing, using a somewhat finer grade of abrasive to bring the lens to an exact curve.

true base curve *See* curve, true base.

true power *See* power, true.

trueing *See* true.

Tscherning's ellipse *See* ellipse, Tscherning's.

turn-back endpiece *See* endpiece, turn-back.

U

ultraviolet Rays having a wavelength somewhat shorter than those at the violet end of the visible spectrum.

uncut A lens that has been surfaced on both sides but not yet edged for a frame.

upcurve bifocal *See* bifocal, minus add.

UV index *See* index, UV.

V

value, Abbé The most commonly used number for identifying the amount of chromatic aberration for a given lens material. The higher the Abbé value, the less chromatic aberration present in the lens. Abbé value is the reciprocal of ω (dispersive power) and is symbolized by the Greek letter *nu*, or ν. In other words, $\nu = \frac{1}{\omega}$. (Synonyms: *nu value, constringence*.)

variant planes *See* planes, variant.

V-bevel *See* bevel, V.

verification power *See* power, verification.

vertex distance *See* distance, vertex.

vertex power allowance *See* allowance, vertex power.

vertical alignment *See* alignment, vertical.

vertical angle *See* angle, vertical.

vertical imbalance *See* imbalance, vertical.

Vertometer Trade name for a type of lensmeter.

virtual image *See* image, virtual.

W

W bridge *See* bridge, metal saddle.

washer, lens Also called *lens liner*, a plastic material that is inserted between a loose lens and the eyewire.

wave A defect in lens surface curvature causing a localized irregular variation in lens power.

wave front *See* front, wave.

wheel differential *See* differential, wheel.

wheel, electrometallic Synonym for electroplated wheel.

wheel, electroplated An abrasive wheel made by electrolytically depositing metal on the wheel in such a manner as to encompass diamond particles. This type of wheel is often used to grind plastic lenses.

wheel, finishing The wheel used in edging to bring the lens edge to its final and smooth configuration.

wheel, hogging Synonym for roughing wheel.

wheel, impregnated Synonym for a metal-bonded wheel.

wheel, metal-bonded Abrasive wheels made by mixing diamond material with powdered metal that is heated in a mold until fusion of the metal occurs.

wheel, roughing An edger wheel that rapidly cuts a lens to near its finished size yet leaves the face of the edge somewhat rough.

width, seg The preedged size of a bifocal or trifocal segment measured horizontally across its widest section.

Wils-Edge mounting *See* mounting, Wils-Edge.

wrap An abbreviated, short form of *wrap-around* or *face form. See* form, face.

wrap angle *See* angle, wrap.

wrap-around A synonym for face form. *See* form, face.

X

X-Chrom lens *See* lens, X-Chrom.

X-ing A vertical misalignment evidenced by a twisting of the frame front such that the planes of the lenses are out of coincidence with each other, forming somewhat of an *X*.

Y

yoked prism *See* prism, yoked.

Younger seamless *See* lens, Younger seamless.

Z

Z80.1 The identification number for the American National Standard for Ophthalmics-Prescription Ophthalmic Lenses-Recommendations.

Z87 The identification number for the American National Standard Practice for Occupational and Educational Eye and Face Protection, which sets standards for safety lenses and frames.

zone, blended The blurred area between distance and near areas on an "invisible" bifocal line (not to be confused with the progressive zone of a progressive addition lens).

zone, progressive That portion of a progressive addition lens between the distance and near portions where lens power is gradually increasing. Synonym; progressive corridor.

zyl file *See* file, zyl.

zyl An abbreviation for the frame material zylonite. Although this material is no longer used, the name is sometimes still used to refer to plastic frames in general.

zylonite An early frame material that accepts a good polish but is flammable at high temperatures. It is no longer used for spectacle frames.

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